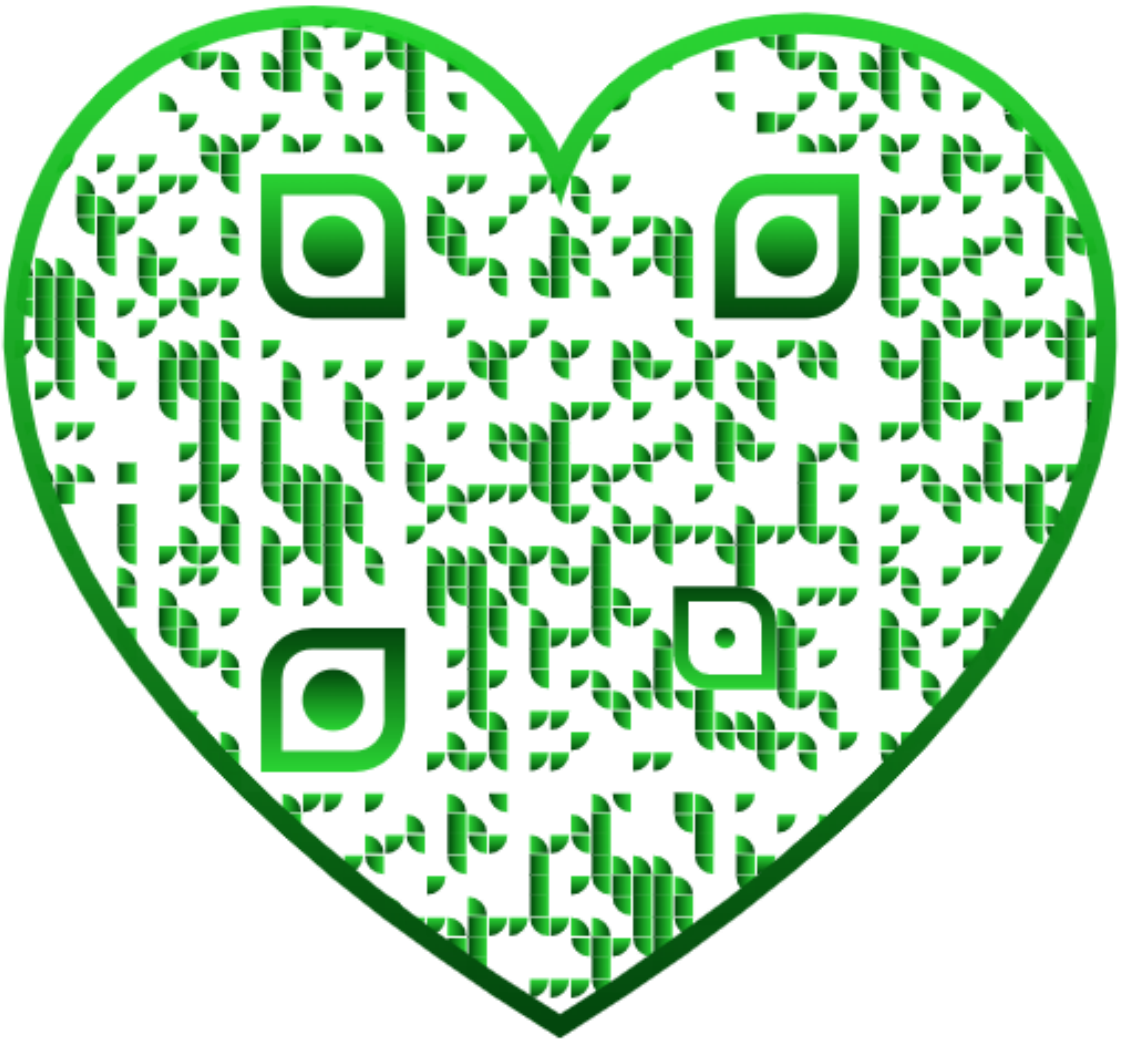
BASIC WELDING FOR FARM AND RANCH

Essential Tools and Techniques for Repairing and Fabricating Farm Equipment

WILLIAM GALVERY



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EDITED BY MICHAEL MARTINDELL

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INTRO-DUCTION

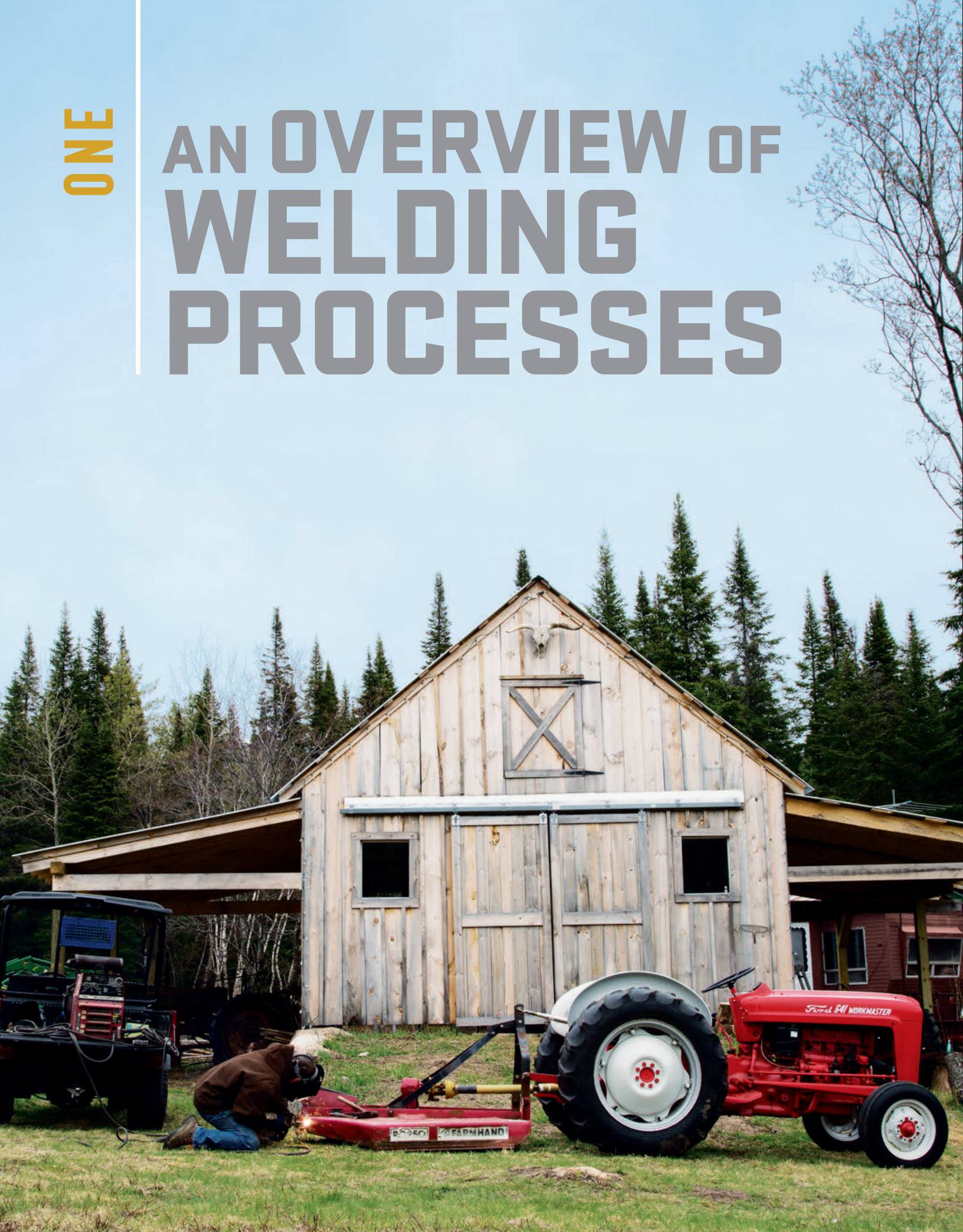
The term *welding* can conjure up some dramatic imagery, like workers clad in leather and dark faceshields producing a shower of sparks from red hot metal. To those not immersed in the industry, dealing with flames and electric arcs that produce temperatures hot enough to melt steel may seem daunting and hazardous, something left to the skilled professionals. Welding, however, has become a useful, do-it-yourself tool for homeowners, farmers, ranchers, car hobbyists, artists, and anyone else with a need to join metal.

Basic Welding for Farm and Ranch is geared toward anyone who wants to learn the basics of welding for their own uses. In this book you will find the necessary information on how to safely set up and use the right equipment for oxyacetylene welding, stick welding (sometimes referred to as arc welding), MIG, and flux-cored welding. We will cover each type of welding's own unique characteristics, applications, and specialized tools.

Knowing how to weld opens up unlimited opportunities for your own repairs and custom fabrication around the home, farm, or ranch. Besides welding, we will also cover the oxyacetylene cutting process, brazing and soldering, and safety precautions. Throughout the book, we offer useful welding tips and do-it-yourself home projects.

ONE

AN OVERVIEW OF WELDING PROCESSES



The term *welding*

comprises a number of different processes for fusing metals. For the home welder, oxyacetylene welding, shielded metal arc welding (also called stick welding), and wire-feed welding processes (MIG and flux-cored wire welding) are the most popular. This chapter also covers the basics of joint preparation and the most common types of welds. For procedures that relate to specific welding processes, see the relevant chapter.

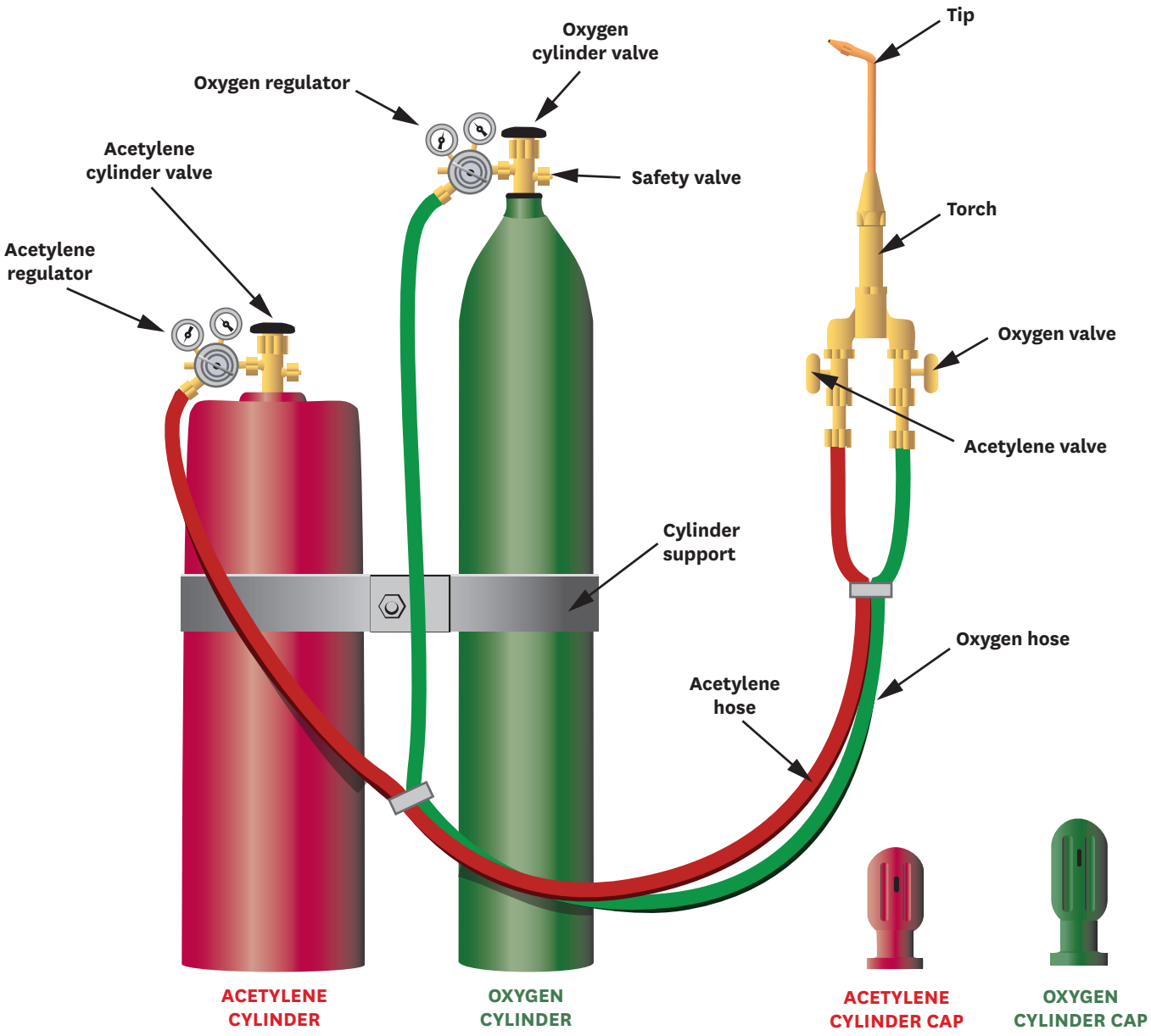
Oxyacetylene Welding

Oxyacetylene welding has been used in factories and on farms since the beginning of the twentieth century. As more efficient and effective welding processes have become available throughout the years, oxyacetylene welding has become less common, making way for the electric arc. Despite this, the oxyacetylene torch is still an essential tool for projects and repair in the shop, garage, or in the field. The process is inexpensive and portable, and its versatility offers a number of important uses, including cutting, hot bending and forming, forging, brazing, and braze welding. We will cover theory, use, and safety precautions/procedures in chapter 3.

A portable oxyacetylene welding setup can be inexpensive and versatile.

Oxyacetylene: How It Works

When combined in the correct proportions in the welding torch handle, oxygen and acetylene gases produce an approximately 5600°F (3100°C) flame at the torch tip. This flame melts the edges of the base metals to be joined into a common pool. Sometimes additional filler metal is added to the molten pool from a welding rod. When this common pool cools and the metal freezes solid, the joined metals are fused together and the weld is complete. The resulting weld should be a homogeneous mixture of the parent material (the parts being welded together) and the added filler material. The weld should be at least as thick as the thinnest parent material section.

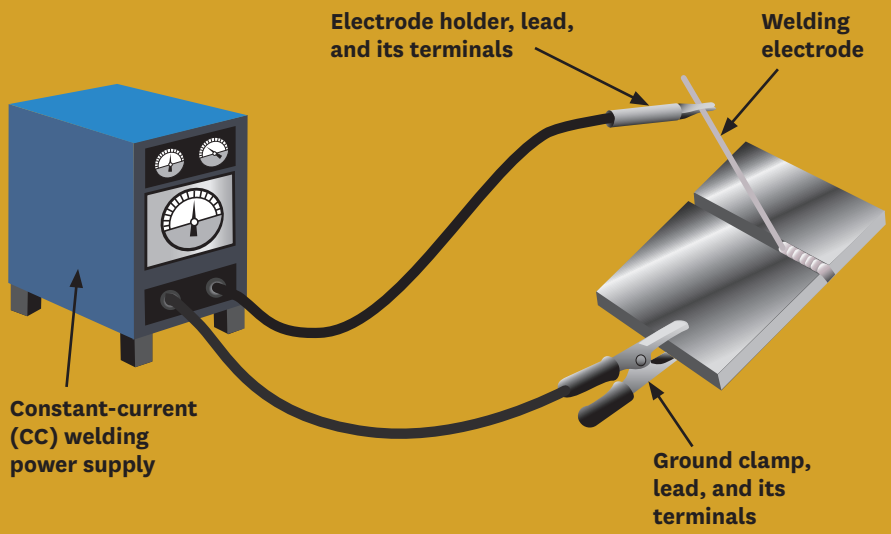


Shielded Metal Arc Welding or Stick Welding

Shielded metal arc welding (SMAW) machines have been used in the United States since the early days of the twentieth century. This form of welding is popular for industrial, automotive, and farm repair because its equipment is relatively inexpensive and can be made portable. More welders have learned this process than any other, and many refer to it as "stick welding." Although it remains a widely used process, it is declining in popularity as wire-feed welding processes (MIG, flux-cored arc welding) continue to gain popularity and market share. Stick welding is a good go-to choice for repairing broken and worn equipment that has been exposed to oxidation, grease, oil, or dirt, due to the cleaning capabilities of the electrode flux coating (which removes contaminants from the working surfaces).

Stick Welding: How It Works

In stick welding, an electric circuit travels from the welding power supply to the electrode (the "stick"), the welding arc, the work, and the work connection, then back to the power supply. Temperatures within the arc exceed 6,000°F (3,300°C), heating and melting both the electrode and the base metal beneath it. As the welder moves the electrode away from the molten pool, the molten mixture of electrode and base metals solidifies and the weld is complete. See chapter 5 for more about stick welding.


Electrode holder, lead, and its terminals
Welding electrode
Constant-current (CC) welding power supply
Ground clamp, lead, and its terminals

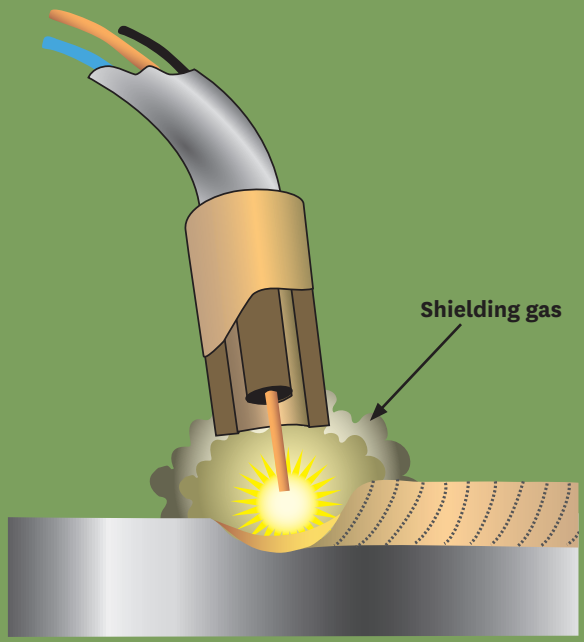
MIG welders contain an internal wire-feed mechanism that feeds welding wire to the gun.

Wire-Feed Welding and MIG Welding

Although the equipment may cost more than arc welding equipment with similar capabilities, a MIG (metal inert gas) welding setup offers higher productivity, and it is relatively easy to learn. Not having to stop a bead, change electrodes, and restart again increases metal deposition rates and reduces weld discontinuities. Because of this, it's one of the most popular welding processes, and can be used for projects ranging from light duty, thin sheet metal auto body repair to fixing a tractor bucket with a piece of thick plate steel, and even for fabricating your own custom welding table.

Wire-Feed Welding: How It Works

In this process, welding wire is fed through a welding gun and serves as both the electrode and the filler material. Welding begins as the section of electrode wire between the tip of the gun and the parent material is heated and deposited into the weld. As the wire is consumed, the feed mechanism supplies more electrode wire at the pre-adjusted rate to maintain a steady arc. A welder must be cautious with MIG welding when the surrounding air movement exceeds 5 mph, because the shielding gas can be blown away. For this reason, flux-cored wire (which does not always require shielding gas) can be a good choice for field work or equipment repair.



ADVANCED OPTION: TIG WELDING

TIG (tungsten inert gas) welding is another popular welding process. It is more difficult to learn and use, but can be skillfully applied when clean, precise welds are needed — especially when welding aluminum, magnesium, or titanium. It is an indispensible tool for the likes of the aircraft industry, auto body restoration, and bicycle building; it can weld the thinnest metals with its precise heat control.

TIG welding works when a continuous arc is formed between a nonconsumable tungsten electrode on the welding torch and the metal workpiece. A foot pedal is commonly used to control the size/heat of the arc, inert gas shields the weld, and a separate filler rod is usually added to the weld pool. Cleanliness of the metals to be welded is critical when utilizing the TIG welding process; therefore, it is generally not a good option for field work.

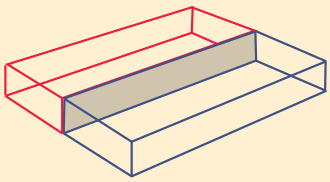
How to Prepare Welding Joints

Joint preparation is the same for all types of welding. The first step of joint preparation is beveling the edges of the joint to create the proper groove. This allows access to the joint interior in order to create more surface area and more depth to the weld penetration, which creates a stronger weld. Without the preparation, the internal portion of the joint would not be fused together, creating a weak joint.

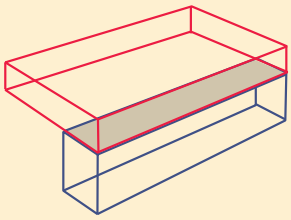
There are many ways to bevel the edges of the joint, and for the purposes discussed in this book, a handheld angle grinder with an abrasive wheel works great for most preparation. For thin sheet metal, a file or pneumatic sander can take down the joint's edges, and for thicker plate steel, the bevel can be flame cut with an oxyacetylene torch, and then cleaned up with the angle grinder.

Proper joint preparation is essential to ensure strong welds. Here, a portable grinder is used to prepare the joint for a repair on this tractor's rear differential.

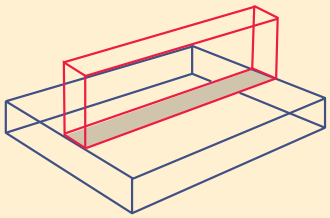
Joint Types



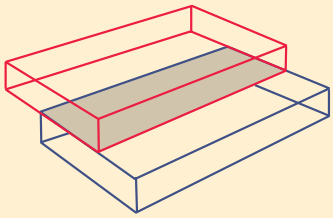
Butt joint



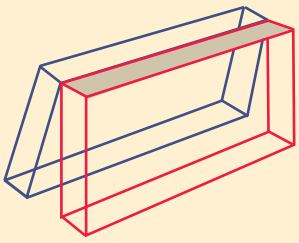
Corner joint



T-joint



Lap joint



Edge joint

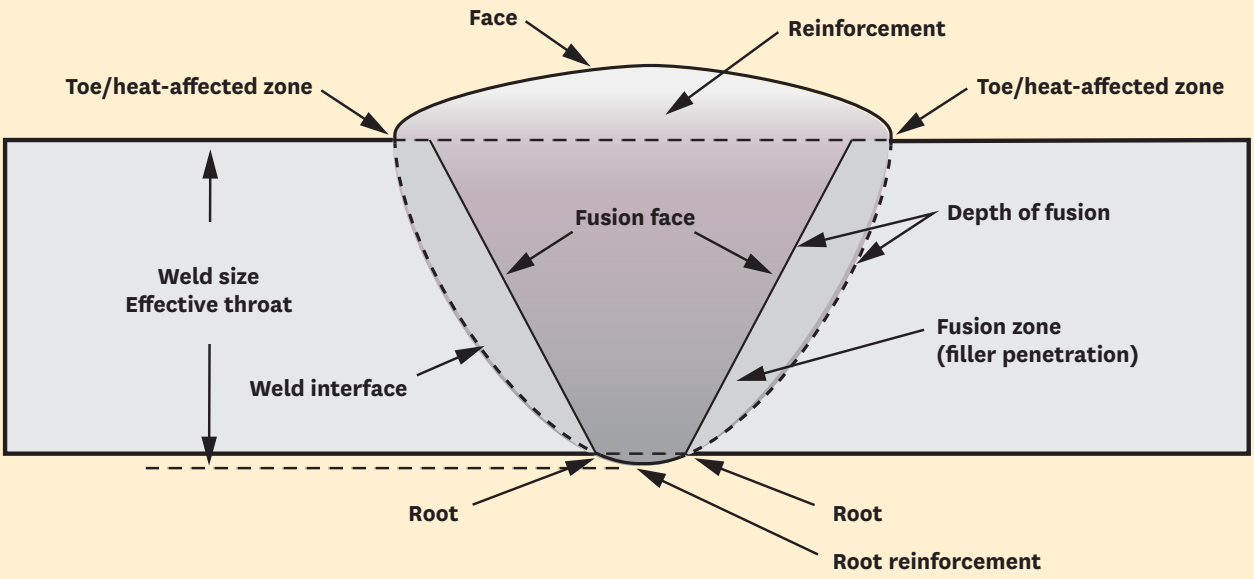
Basic Types of Welds

When you're learning to weld, you'll want to begin by running practice beads. Use a weld bead comparison chart (see page 73) and learn to make the proper adjustments to the equipment and your technique in order to consistently produce a correct bead. Once you're comfortable with the basic principles of a simple bead, you can begin experimenting with specific welds including the groove weld, fillet weld, plug weld, and intermittent weld.

GROOVE WELD

As the name implies, this is a weld made in a groove between workpieces, giving access to the joint's interior.

Parts of a Groove Weld



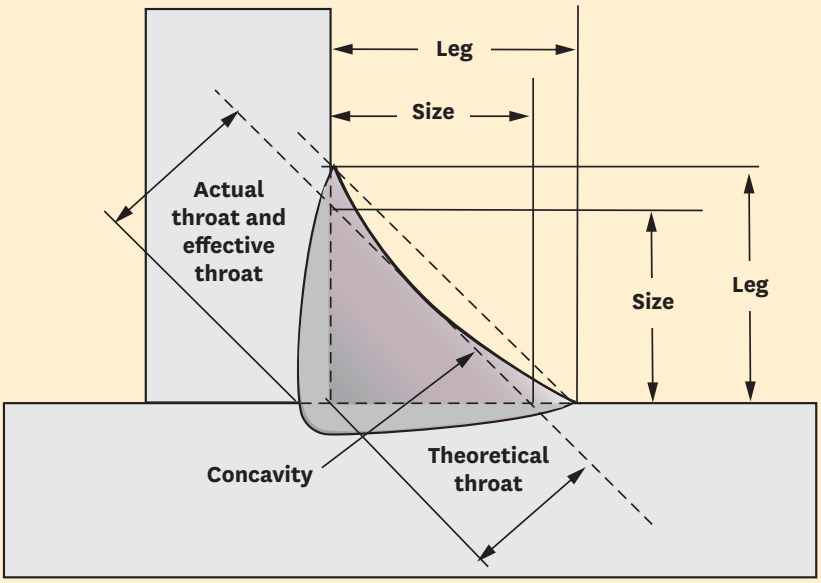
FILLET WELD

Fillet welds are triangular in shape and are used to join materials that are at right angles to each other in a lap, T-, or corner joint. The face of the weld can be convex or concave.

PLUG AND SLOT WELDS

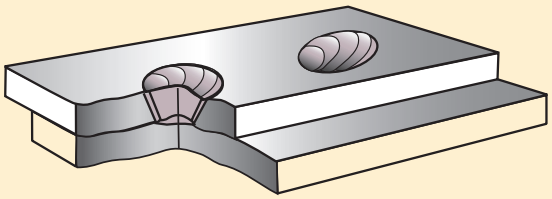
These welds join two (or more) parts together by welding them at a point other than their edges. They are particularly useful in sheet metal and auto body work where welds can be completely concealed by grinding and painting. A hole or slot is made in the workpiece facing the welder, and the weld is made inside the hole. Filler metal completely fills the hole or slot and penetrates into the lower workpiece(s), securing them together. Plug welds are round, while slot welds are elongated and rounded at the ends.

Parts of a Concave Fillet Weld

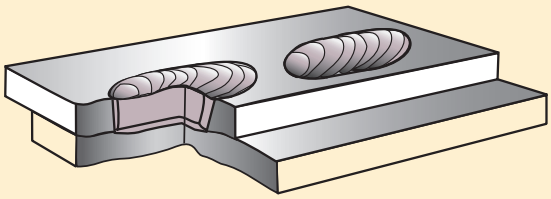


These parts of a weld determine its strength and effectiveness.

Plug and Slot Welds



Plug weld



Slot weld

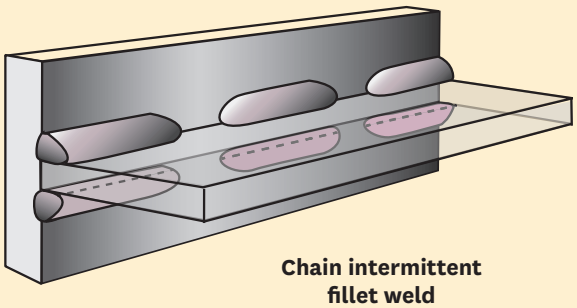
INTERMITTENT WELDS

Also called stitch welding, intermittent welding is commonly used to weld thin metals, such as in auto body repair. This is an alternative to a continuous weld bead, which can result in blowing through (burning through) thin materials.

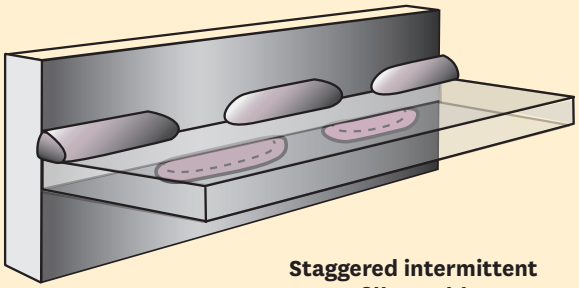
TACK WELD

Tack welds are small, initial welds made along joints to hold the workpieces in place so the parts remain in alignment when they are welded. Tack welds hold work firmly in position but can be broken with a cold chisel if further adjustment is needed. Beginning welders tend to make them too small. The standard length of a tack weld is 1 inch. A tack should be as strong as the weld itself as it becomes an integral part of the finished weld. On thicker metals, always bevel the joint before tack welding to achieve proper penetration.

Intermittent Welds



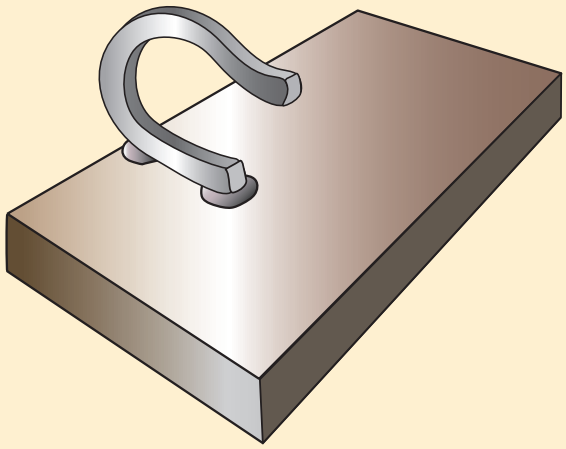
Chain intermittent fillet weld

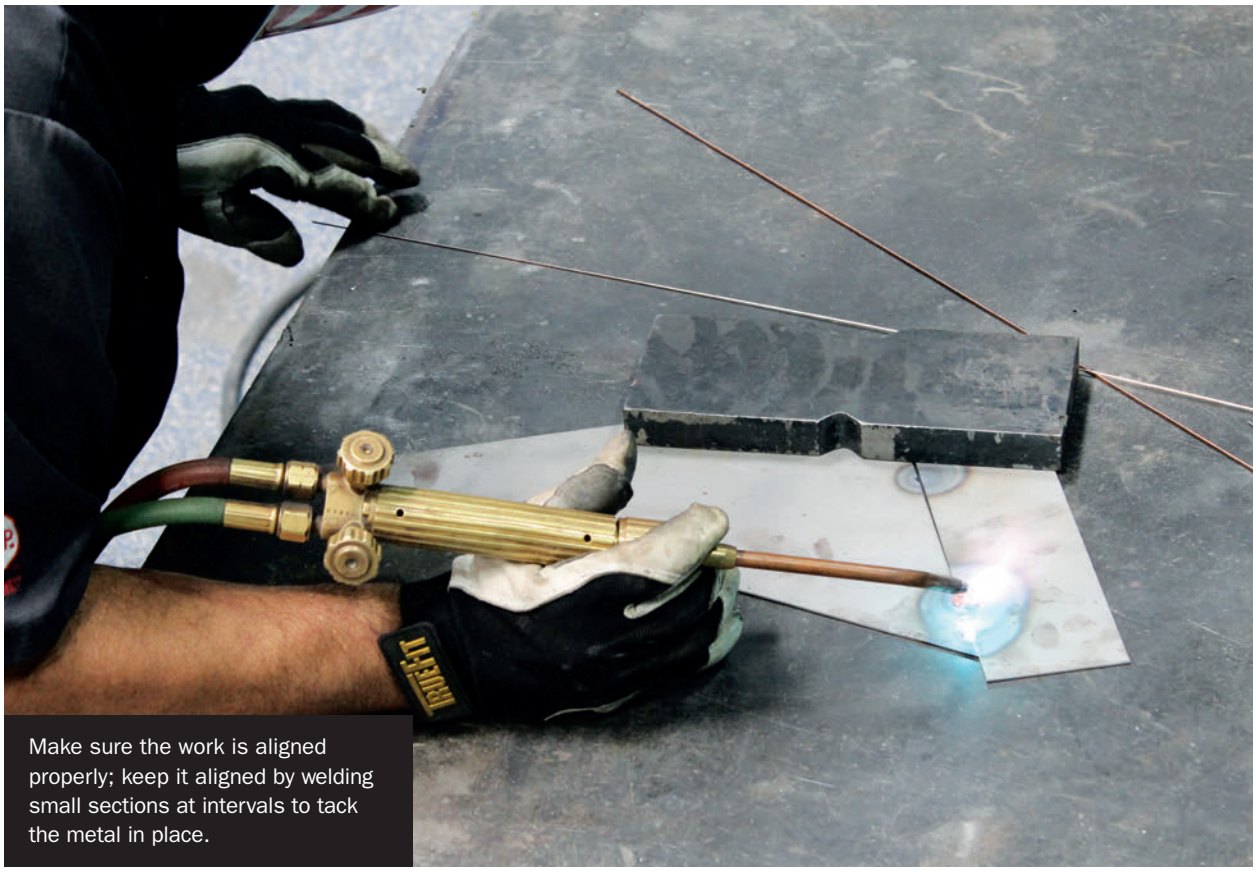


Staggered intermittent fillet weld

Tack Weld

A tack weld holds the hook firmly in place while the welder joins the rest of the hook to the tractor bucket.





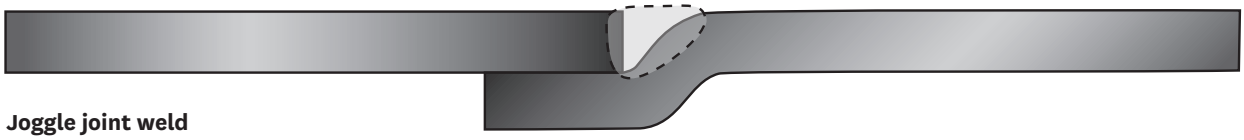
Make sure the work is aligned properly; keep it aligned by welding small sections at intervals to tack the metal in place.

STRINGER AND WEAVE BEADS

With a stringer bead, the path of the electrode is straight, with no appreciable side-to-side movement, and it is parallel to the axis of the weld, making it a good choice for welding thin metal. A weave bead has a side-to-side motion, which makes the weld bead wider (and the heat-affected zone larger) than that made with a stringer bead.

JOGGLE JOINTS

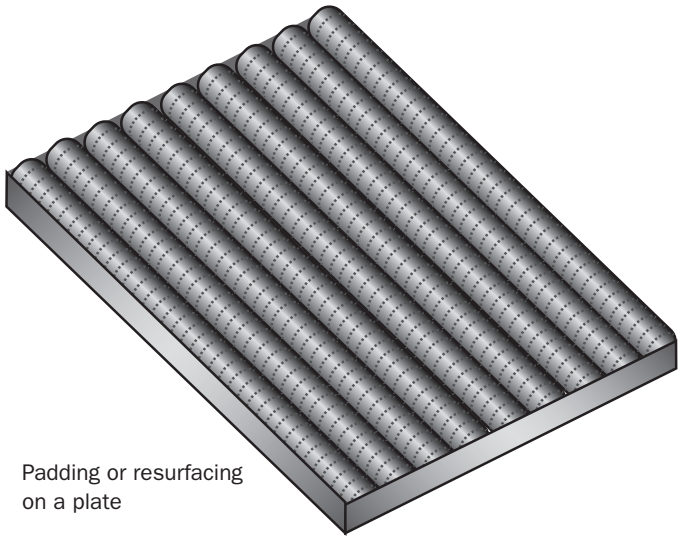
Joggle joints are used where a strong joint and flat surface are needed to join two pieces of sheet metal or light plate. A sheet metal bending tool can be used to put the joggle into sheet metal. They are useful whenever a finished surface concealing the weld is needed and where a butt joint would not work with thin sheet metal.



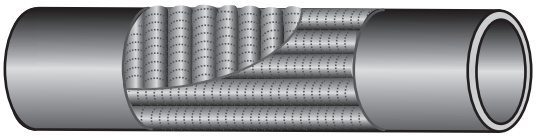
Joggle joint weld

PADDING

Padding is a technique of applying filler metal to a surface to make a plate thicker or to increase the diameter of a shaft. It is used either to restore a dimension to a worn part or to apply an extra hard-wear surface, such as on an excavator bucket.



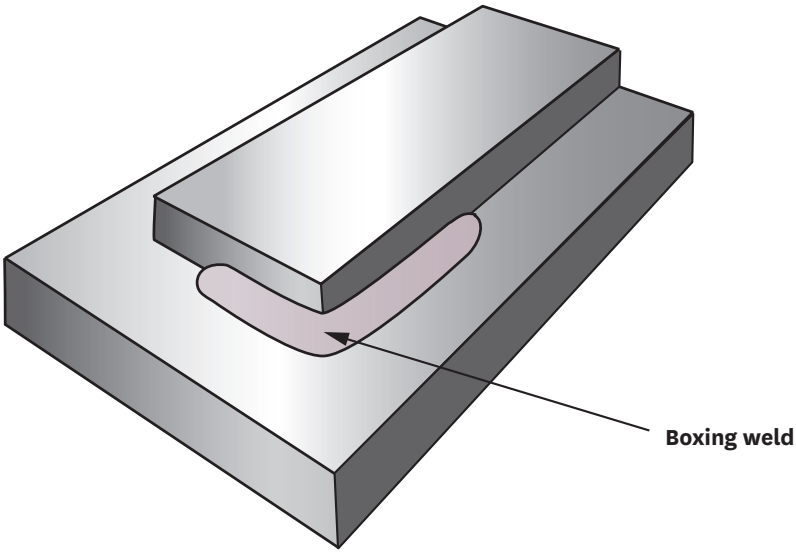
Padding or resurfacing on a plate



Padding or resurfacing on shaft, bar, or pipe; axial (perpendicular to pipe length) and circumferential (parallel to pipe length) welds

BOXING

A boxing weld is a fillet weld that continues *around* a corner. Typically, a fillet weld is made from one abrupt end of the joint to the other abrupt end of the joint. This can help limit or distribute stresses on the welded corners or ends.



Special Procedures for Welding Thick Plates

By learning a few simple procedures for joining thick plates you'll be able to tackle jobs that you may have assumed were only possible with professional or industrial welding equipment. The use of backing plates, runoff plates, and patterns for multiple-pass welds will allow you to easily join thick plates.

ROOT-PASS WELD

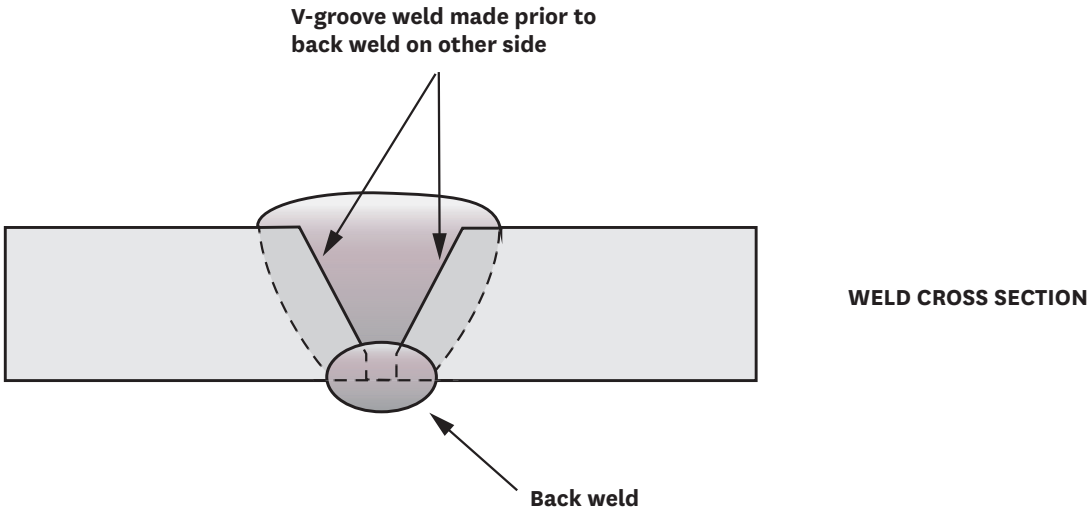
A root pass uses weld filler metal to close the root space between the weld faces. It is especially helpful in welding pipe and thick plates where only one side of the weld is accessible and no backing material is used. Two goals of the root pass are getting complete penetration of the weld and minimizing hydrogen contamination from below. Improper joint preparation, choosing the wrong welding rod, failing to preheat the base metal, incorrect amperage, and contamination of the weld from below are common mistakes that prevent a sound root pass.

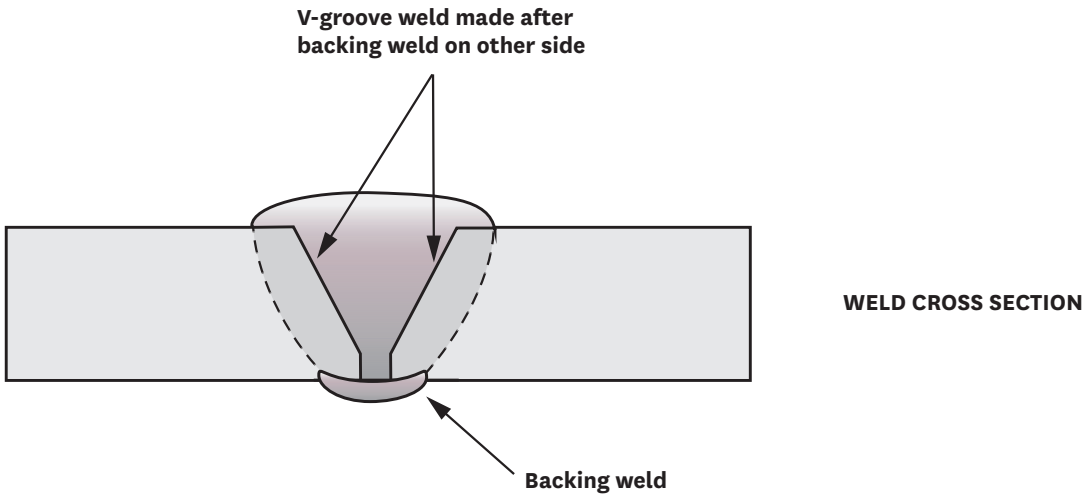
Welding thick plates such as these often requires specialized techniques.

BACK AND BACKING WELDS

A back weld is applied after a groove weld is completed. The back weld is made to ensure full penetration through the material being joined. Before applying a back weld, you must grind or gouge into the bottom of the groove weld until you reach sound weld metal (to remove weld material with porosities or slag inclusions). Then you can apply the back weld to the bottom of the groove weld.

A backing weld is applied to the bottom or root of a groove weld before the groove weld is applied. Because the root or bottom of the weld is made first it becomes a backing for the groove. The difference between a back weld and a backing weld is the sequence of welding. Before the groove weld is completed the backing weld must be ground or gouged to sound weld metal.

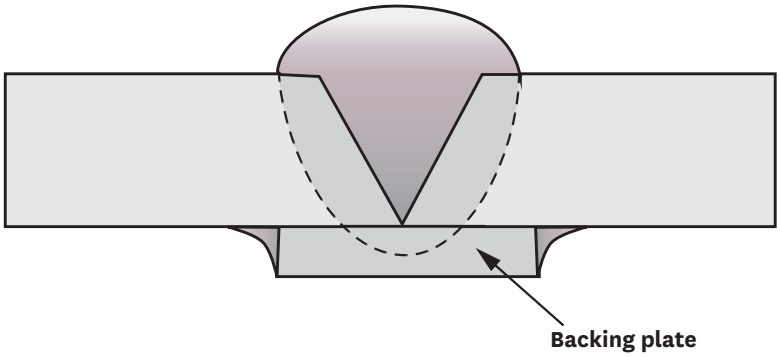




▲ Both the back weld and backing weld are common ways to reinforce a weld.

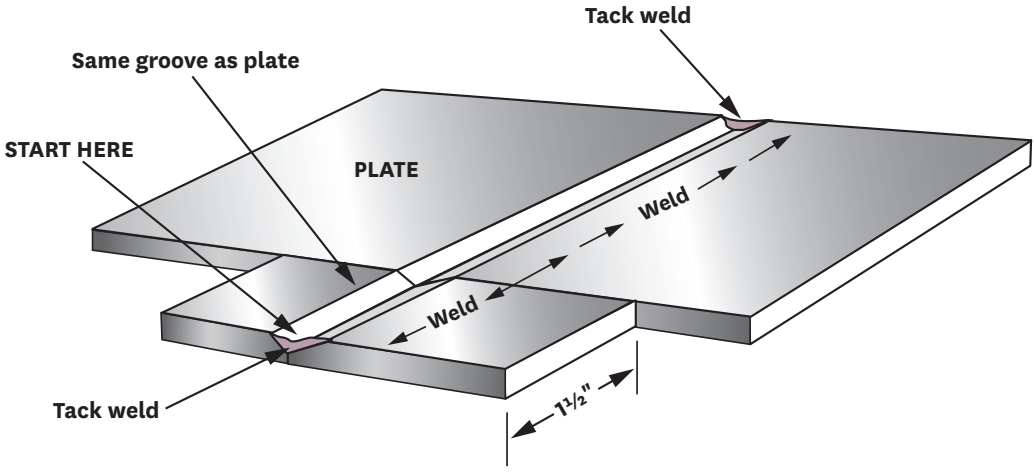
BACKING PLATES

A backing plate contains the large weld pool created when joining two thick sections that are accessible from only one side. It takes the place of a root pass. The backing plate also shields the weld pool from atmospheric contamination (such as moisture and hydrogen) coming in from the back of the weld. Backing plates are usually tack welded to two sections of the weld, but there are proprietary ceramic tapes and metal-glass tapes that perform the same function and do not need to be tacked into place. Copper and other materials are also used as backing plates, as the weld shouldn't adhere to them. Backing plates can also be used as a heat sink when welding thin materials where heat buildup and blow-through can be a problem.



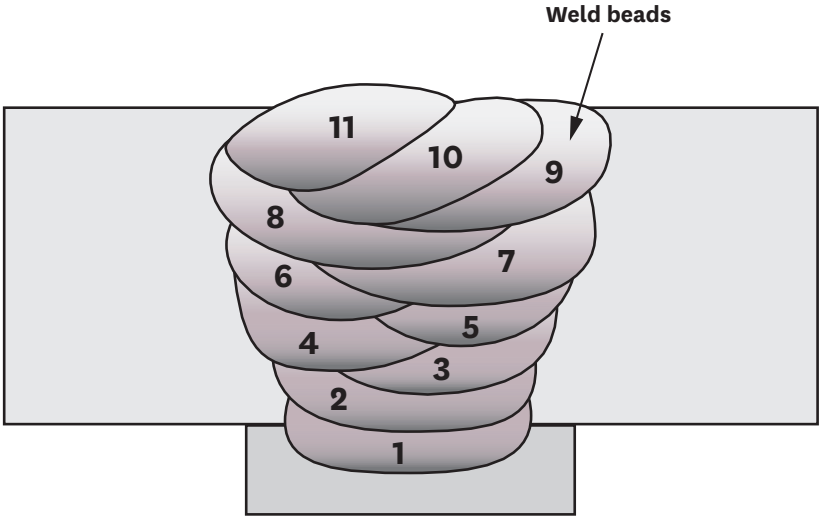
RUNOFF PLATES

A runoff plate prevents the discontinuities caused by beginning and ending the welding process. The plate is made of the same material as the work being joined. It is tack welded to the joint at the start and/or end of the groove joint. The runoff plate contains a groove like the pieces being joined.



MULTIPLE-PASS TECHNIQUE

When you are faced with making a large weld to join thick plates, with limited amperage or deposition rate, use multiple passes of parallel weld beads. The benefit of this technique is that each sequential pass tends to anneal and reduce stresses in the resulting welds below.



SLAG REMOVAL

Slag is a by-product resulting from dissolved flux and nonmetallic impurities that form during the welding process. It must be removed between weld passes or the remaining slag will form inclusions *within* the weld metal and weaken it. Slag is usually removed with a slag hammer, but a wire brush, angle grinder, wire wheel, or pneumatic peening tool may also be used. In pipe welding, grinders and power wheels are used between each welding pass to ensure a slag-free surface on which to begin the next pass. Hint: If proper amperage and temperatures are reached, slag will usually come off a lot easier, especially with low-hydrogen welding rods.

To ensure a strong weld, remove slag between passes.

Welding vertically means working against gravity. It's sometimes necessary, but requires extra skill.

Out of Position Welding

Generally, flat and horizontal fillets (T-joints and lap joints) are optimum for achieving quality welds. Because you can't always change the orientation of the material you are working on, however, you may find yourself having to weld vertically, overhead, and on pipe that is in a fixed position and can't be rotated.

When welding out of position, you are welding against gravity. This requires not only practice and skill, but for each of the welding processes there are different variables that need to be adjusted in order to weld in all positions.

HOW TO IDENTIFY THE METAL(S) YOU'RE GOING TO WELD

- **Use a magnet to see if the metal is ferrous (contains iron and is therefore magnetic), such as steel or iron**
- **Evaluate the application for use. Is it high strength, wear resistant, or corrosion resistant?**
- **Look at the construction of the object. Is it cast or forged? Is it welded? Is it soldered or brazed?**
- **Contact the manufacturer of the object.**
- **Perform a spark test. (See page 43.)**

GARDEN RAKE REPAIR

The ends of a garden rake bow represent a weak point that often breaks. A trip to the metal bin at the local recycling center is likely to produce a rake that simply needs a tack weld to return it to service.

1

Use locking pliers specifically made for welding applications to hold the two work surfaces in position during the tack weld.

2

Lay down a beefier weld (compared to the original) for greater durability.

3

Remove the slag.

In less than 5 minutes, you've made a repair that's better and will last longer than the original weld.

TEN-MINUTE HORSESHOE HOOKS

Old horseshoes make great welding stock for a variety of projects. Here's an assortment of both draft- and pony-sized shoes.

1

Clean up the welding surface on each shoe with a grinder and then practice fitting the two pieces together. We opted for a simple design mounting one hook perpendicular to the first.

2

A tack weld holds your work in place and allows you to check for alignment. If you're off, use a cold chisel or grinder to break the weld.

3

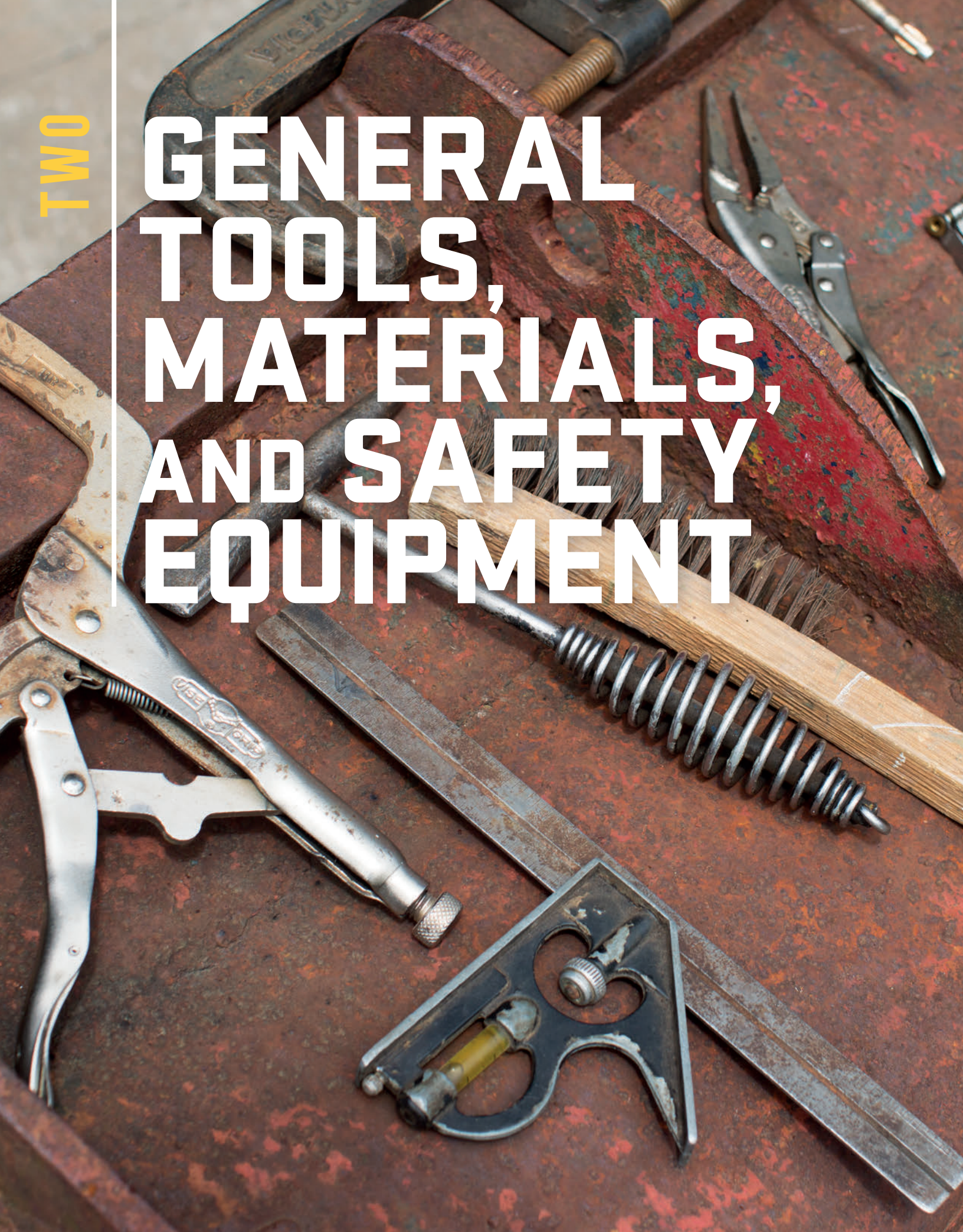
Once you're happy with your work, continue welding on opposite sides.

4

Clean up your new hook with a wire wheel and then apply a clear coat to prevent rusting, or leave untreated for a natural patina.

TWO

GENERAL TOOLS, MATERIALS, AND SAFETY EQUIPMENT



Each welding process

requires specialized equipment to do the job. But welding, whether you use it for hobby purposes or to fix a broken machine, requires a number of common hand and power tools. Many of these tools you may already have in your toolbox; others you may need to purchase. One thing is certain: you'll need a wide assortment of clamps to hold the work in position, both to keep the work steady while you weld and to reduce weld-induced distortion. Often you are faced with straightening out a bent or twisted object, which may require using extra heat, certain hand tools for prying and leveraging, or just a big sledgehammer. The metals you will be working with all have different characteristics and react differently under the intense heat of the welding torch. This chapter will look at some of the properties of those metals, as well as the safety equipment required for working with them.

Combination square

Cold chisel and ball peen hammer

Common Hand Tools Used in Welding

You may already own many of these tools because they are commonly used for general carpentry and household repair. Some ordinary tools that you should have for welding include:

- **BUILDER'S AND TORPEDO LEVELS.** Use the larger builder's level whenever possible; it is more accurate and measures over a longer span. Use the torpedo level wherever the builder's level won't fit.
- **FRAMING, RAFTER, TRY, AND COMBINATION SQUARES.** Use the largest square that fits the work. The combination square is convenient for layout of 45-degree corner cuts and parallel lines.
- **COLD CHISEL AND BALL PEEN HAMMER.** These are handy for breaking tack welds when they must be repositioned; also useful for removing material between a series of drilled holes (chain drilling).
- **CENTER PUNCH.** This marks hole centers and cutting lines.
- **COMPASS AND DIVIDERS.** These are for scribing circles or stepping off a series of equal intervals.
- **FILES.** These are used for bringing an oversized part down to exact dimension or removing a hazardous razor/burr edge.
- **HACKSAW.** This enables slow but accurate metal cutting.
- **TAPE MEASURES.** In most cases, 16- and 24-foot tapes are the most convenient sizes. They are useful for measuring on curved surfaces, too.
- **PRECISION STEEL RULES.** These are available in lengths from 6 to 72 inches.
- **PROTRACTOR.** This is used for finding angles.

- **TRAMMEL POINTS.** These points fit on and adjust along a wood or metal beam and scribe circles or arcs with 20- to 40-inch diameters.
- **SLEDGEHAMMER.** For straightening, realigning, or removing bolts or pins.
- **PRY BARS.** Small and large, to manipulate objects.
- **HYDRAULIC JACK.** To straighten or support objects.
- **COME-ALONG.** To pull parts back together.
- **CHAIN FALL.** To lift heavy objects safely.

SPECIALIZED HAND TOOLS

Here are some more specialized tools most welders will find necessary:

- **SHEET METAL SHEARS OR TIN SNIPS.** For cutting thin sheet metal.
- **CHIPPING HAMMER.** To remove welding slag.
- **WIRE BRUSH.** For cleaning welds.
- **PLIERS.** For moving hot metal safely.
- **WIRE CUTTERS.** To trim electrode wire.
- **MIG WELDING PLIERS.** For moving metal, trimming wire, and for cleaning spatter from the contact tip and nozzle.

Sheet metal shears

Chipping hammer

Wire brush

MIG welding pliers

Soapstone can also be used for marking metal; it's called welder's chalk.

METAL-MARKING TOOLS

There are a variety of tools used to mark metal layout lines. They include:

- **WELDER'S CHALK/SOAPSTONE OR CHALK LINE.** These are used for marking rough dimensions or to indicate cutting lines that will hold up under cutting torch heat.
- **BALLPOINT METAL MARKER.** Metal markers put down a 1/16-inch-wide line, come in several colors, and are excellent for applying lettering to metals. They are rated at 700°F (371°C) so cannot be used for torch cutting lines. Note that some marking materials' residues may contaminate GTAW (gas tungsten arc welding) welds.
- **CENTER PUNCH.** A line of center punch marks can be more accurate than marking with chalk or pen, and will also withstand torch heat.
- **AEROSOL SPRAY PAINT AND SCRIBER.** For very accurate layout lines, spray-paint the metal in the area of the layout lines and use a scriber to scratch through the paint to make the layout lines.
- **SCRIBER ON BARE METAL.** A scriber can be used to mark layout lines on bare metal. Do not use scribe marks to designate bend/fold lines, however, since they will be stress-raisers and the part will eventually fail along the scribed line.
- **MACHINIST'S LAYOUT FLUID.** This can be used to make scribed lines more visible. These lines will not hold up under torch heat but can be essential to laying out lines that won't be cut with a torch. A black felt-tip pen can also be used in place of spray paint or layout fluid to darken the metal and highlight scriber lines.

This yellow marker is specially designed for drawing layout lines on metal.

Common Power Tools Used in Welding

Many of the power tools used by welders are also used for carpentry and other tasks. They include:

- **RECIPROCATING SAW.** Excellent for rough cuts of any shape on bar stock, pipe, and plate.
- **HANDHELD BAND SAW.** Capable of accurate cuts and following scribed lines; excellent for both pipe and tubing. Its throat is too small for most plate cutting.
- **ELECTRIC DRILL AND BITS.** For starter holes to begin oxyfuel cutting, holes to install hardware, and for chain drilling.
- **ABRASIVE CUTOFF SAW.** Good for rod and pipe. Not good for shapes and tubing. Difficult to make accurate cuts.
- **ANGLE GRINDER WITH VARIOUS ATTACHMENTS.** Take down rough edges and remove bad welds with a grinding wheel; smooth edges, take down lighter material, and sand metal surfaces with different grit sanding wheels and abrasive flap wheels; use a thin cut-off wheel to cut and trim metal workpieces to size; remove mill scale, paint, and rust with a wire wheel or wire cup brush. Portable, battery-operated angle grinders are sufficient when there is no available electricity source, but corded, plug-in grinders are more efficient.
- **BENCH GRINDER/PEDESTAL GRINDER WITH ABRASIVE AND WIRE WHEELS.** Same as portable grinder, but here the operator holds the parts.
- **DIE GRINDER.** To get into tight places and to grind in pinor bolt holes.

▲ A portable grinder outfitted with either a wire wheel or a sanding wheel is a handy tool for prepping metal before welding.

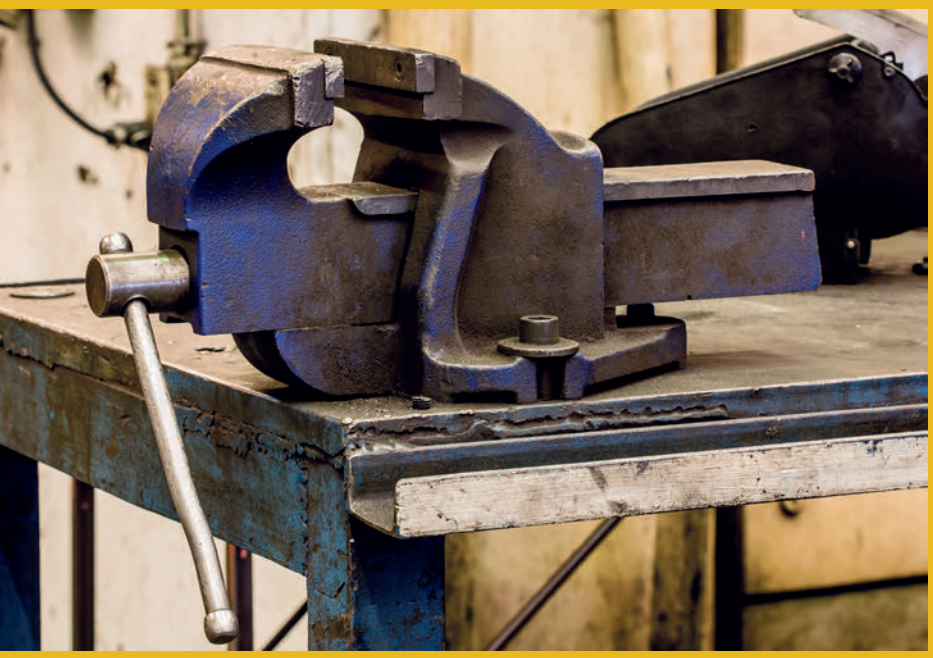
◀ A bench grinder is powerful and helpful for detail work.

◀ A metal chop saw is a good option for cutting metal. Be sure to wear ear muffs and safety glasses when operating it.

Welding Tables and Clamps

A welding table places the work at a comfortable height and allows welders to concentrate on their work rather than their discomfort, and it can be used to make some welds while sitting down. Also, it provides a stable, flat surface to position and clamp work prior to welding. In some applications the work itself may be tack welded to the table, and the weld-tack beads are ground off afterward. For oxyacetelene cutting applications, it is helpful to have a welding table with a grate section and metal catch barrel underneath for catching cutting slag or depositing welding.

Clamps play a critical role in holding the parts to be welded in the proper position to make the weld and in preventing weld-induced distortion. Welders use a variety of general-purpose clamps and clamps specifically designed for welding projects.



▲ A heavy duty bench vise provides a simple way to strongly secure workpieces for different welding and metal working techniques.

▲ A portable welding table is useful when working in remote locations.

► Clamps are essential for holding in place the pieces you're welding together.

Common Steel Products Used in Welding

The most commonly used metal in fabrication and repair is hot-rolled, low-carbon steel. It comes in solid shapes, sheet metal, plate steel, pipe, square and rectangular tubing, thin strips, and thicker strips known as flats. Large steel distributors also stock I-beam, H-beam, channel iron, diamond plate, and different types of expanded steel. Less common sizes and shapes of steel are usually available on order, as well as alloy steels, stainless steel, bronze, brass, copper, and aluminum. These metals are substantially more expensive than low-carbon steel.

Sheet and plate generally come in 4 × 8-foot pieces, and solid shapes and tubing come in 20-foot lengths. For a small charge (or sometimes no charge at all), the distributor will cut the material for easier transport, or cut the pieces to size for your project's needs on their giant band saw, saving you plenty of cutting time. Remember to bring some work gloves for handling the greasy, sharp-edged material.

Large steel distributors also have a variety of remnant material that is sold by the pound. This can be economical, especially if you need a smaller but thicker, heavier material, and don't want to buy a whole 20-foot length. A tape measure and calipers can also help you determine if a particular remnant will be useful. Furthermore, when planning projects, remember that one size of tubing (either round, square, or rectangular) is dimensioned to telescope or slide smoothly into the next larger size. This is particularly useful when fabricating portable equipment.

OTHER HARDWARE ITEMS

Common hardware items used by welders include:

- **NUTS.** By welding a nut over an existing hole you can add threads without tapping them; this facilitates adding leveling jacks, adjustment members, and clamps. You can also weld a nut over a broken stud or bolt, enabling you to turn and remove the stud with a wrench.
- **BOLTS.** These can be used for axles, swivel points, and leveling jacks, and for locating pins. Bolts can also be cut to provide just the threaded portion for threaded studs, or just the rod (unthreaded) section for swivel pins.
- **ALL-THREAD.** This is rod stock threaded end-to-end and useful where clamping or positioning action is needed. (Note: It is usually a low grade for minimal strength.)
- **MACHINE SCREWS, SHEET METAL SCREWS, POP RIVETS.** These can be used to fasten metal for temporary repair or when welding may not be an option. Predrill holes with a sharp bit and cutting fluid.
- **HINGES.** There are three main hinge designs:
  - **Leaf hinges for welding.** These hinges are not plated and have no screw holes.
  - **Cylindrical weld hinges.** These are made in a wide variety of sizes and can support heavy loads.
  - **Piano hinge.** Provide continuous support along a door or cover.
- **CASTERS AND WHEELS.** These are better purchased than made in the shop.

Keeping a scrap metal collection for welding projects around the farm keeps you from having to run to town every time you need to make a repair.

QUICK TIP: USING SPARKS TO ID METAL

Your grinder is not only handy for surface prep; it's also useful for identifying types of metals. Once you have identified the type of metal based on the sparks (or lack of spark), you can then determine which process will be necessary, as well as what type of welding rod or electrode to use for your project.

NOTE: The safest way to hold a grinder is with *both* hands.

▲ **If no spark: you're likely dealing with a nonferrous metal like aluminum.**

▼ **If little spark: you're likely dealing with carbon-rich metal like high-carbon steel.**

▼ **If lots of spark: you're likely dealing with mild steel.**

ALUMINUM

BRASS

COPPER

STEEL

Suggestions for Welding Various Metals

Metal Welded	Technique and Potential Problems	Flux Used	Flame Type	Suggested Rod
Aluminum (Al)	Al does not show color change before melting and has poor hot strength. Tack joint before welding. Remove all flux after welding.	Al flux	SR	Match base metal
Brass	Braze	Borax	SO	Navy brass
Bronze	Braze	Borax	SO	Copper-tin
Copper	Braze	—	N	Copper
Iron, gray cast	Preheat to prevent cracking. Weld at dull red heat. Flux applied to rod by dipping hot rod into flux. Allow joint to cool slowly or it will crack.	—	N	Copper
Iron, malleable cast	Welds to poor strength. Better to braze weld using bronze rods.	Borax	N	Bronze
Iron, wrought	Weld or braze	—	N	Steel
Steel, low-carbon	Weld or braze	—	N	Steel
Steel, medium-carbon	Weld or braze	—	SR	Steel
Steel, high-carbon	Weld or braze	—	SR	Steel
Steel, low-alloy	Weld or braze	—	SR	Steel
Steel, stainless	Weld or braze	SS flux	SR	Match base Metal

SR = Slightly Reducing SO = Slightly Oxidizing N = Neutral

Cleaning and Preparing Metals for Welding

Some welding processes are fairly tolerant of mill scale (the flaky surface of hot-rolled steel), and small amounts of rust and paint, so it is possible to make good welds on most steel as it comes from the mill. However, the metal must not be greasy. For this reason, most hollow products — like pipe, tubing, and hollow rectangular shapes, which are shipped from the factory well-oiled — must be degreased before welding.

Household cleaners like Simple Green or Formula 409 All Purpose Cleaner will work; industrial degreasers like denatured alcohol and acetone can also be used. Paint stores, metal supply houses, hardware stores, and pool supply stores often carry phosphoric acid (dilute in 4 to 10 parts water). These stores may carry trisodium phosphate (TSP), also a good cleaner. Do not clean hollow steel shapes too far in advance of welding or they will rust. Do not use compressed air to dry them off, as this will reintroduce oil contamination from the compressor. Use a plastic bristle brush or a stainless steel brush because copper, brass, or aluminum brushes will contaminate the weld.

Thorough preparation is especially important when you're not working with metal straight from the factory.

STEPS FOR PREPPING METAL

Metal preparation generally requires some amount of grinding, sanding, and cleaning with the use of solvents or chemicals. Take precautionary steps to protect your respiratory system from dust contaminants and/or harmful vapors produced when prepping metal.

- Grind, using wire brush with a grinder; use flap wheels, emery cloth, and bead/sandblast to remove all mill scale, rust, paint, and dirt. Get down to fresh metal.
- Wipe the cleaned weld area with alcohol or acetone to remove residual grease.
- Remember not to cross-contaminate your wire brush, emery cloth, or flap wheels by using the same ones on both steel and stainless steel. If you will be working with both steel and stainless steel, paint the handles of the brushes red for use on steel, and green for use on stainless. This prevents cross-contamination.

SANDBLASTING

One of the secrets to strong, durable welds is to make sure your working surfaces are clean. This means removing rust and paint prior to welding. While a wire brush or grinding wheel is most common for this sort of prep, a sandblaster is ideal for prepping metal that will be primed/painted.

Small parts can be cleaned in a blasting cabinet, which is less messy because it contains the blasting medium. For larger parts, or for those with an outdoor workspace, a canister-type sandblaster can be used. Make sure the sand or blasting media is kept dry, and the sandblaster nozzle is sized to match the blasting media. If you're not using a self-contained blasting cabinet, be sure to wear proper safety equipment; this includes a welding hood, leather gloves, and covering all exposed skin.

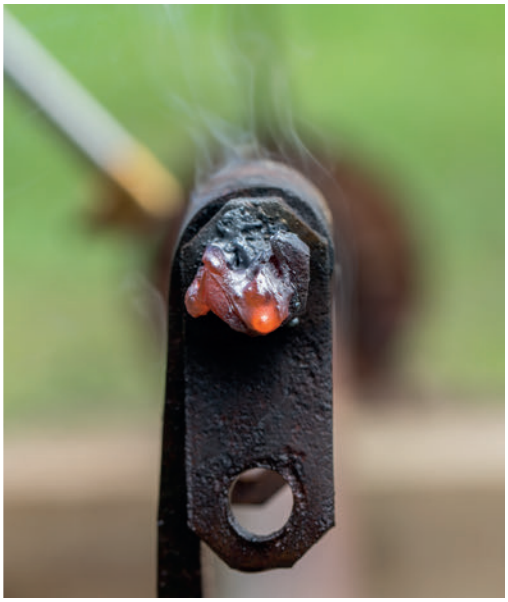
▲ Sandblasting is helpful in preparing metals that will be painted.

► If you're using a canister-type sandblaster, be sure to wear a protective hood and gloves, and cover all exposed skin.

◄ A blasting cabinet is less messy and contains the blasting medium.

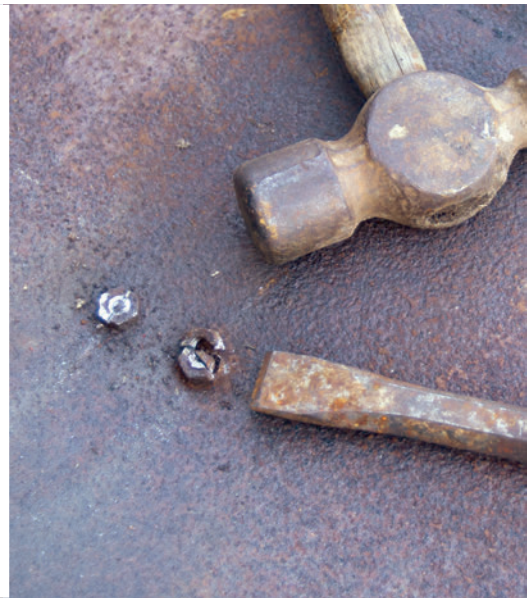
FIVE WAYS TO REMOVE STUCK BOLTS

Heat with a torch. When metal is heated it expands, allowing rusty and seized parts to come apart. Propane torches generally don't produce enough heat; instead use an oxy-acetylene torch and heat it just until the metal begins to take on color. Heating it too much will risk breaking the bolt, so go slowly.



Cut with a torch. If heat alone doesn't get the job done consider using an oxyacetylene torch to cut each side of the nut, and then remove with a hammer/chisel. Since the bolt is a separate piece than the nut, it's easy to penetrate the nut without damaging the threads of the bolt.

Cut with an arc welder. The trick is to use a small diameter (we used 3⁄32") 6011 rod and 85–90 amps DC+ to penetrate the nut/bolt. While the cut is somewhat crude, it's effective for a field repair when equipment is limited.



Split the nut with a cutting wheel. If the shoulder of a nut is rounded off, it may be impossible to get a grip with a wrench or pliers. An angle grinder with a thin cutting wheel can be turned perpendicular to the nut and sliced down the center. Cut about 90 percent of the way through the nut/bolt and then finish splitting the nut with a chisel and hammer.

Spray and tap. In many cases a quality penetrating lubricant (such as PB Blaster) followed by light taps with a hammer is all that's needed to loosen the rust and allow the lubricant to work into the threads. Plan ahead and spray your rusty bolts the night before you need to loosen them. This will give the penetrating lubricant ample time to work.

Lay down a soaked blanket before welding to avoid combustion from sparks or hot slag.

Protecting Equipment and Surroundings

Welding and cutting produce a source of combustion from the molten metal, slag, and sparks from grinders. Take proper precautions to prevent fire and other damage to equipment, paint, glass, and electronics, such as:

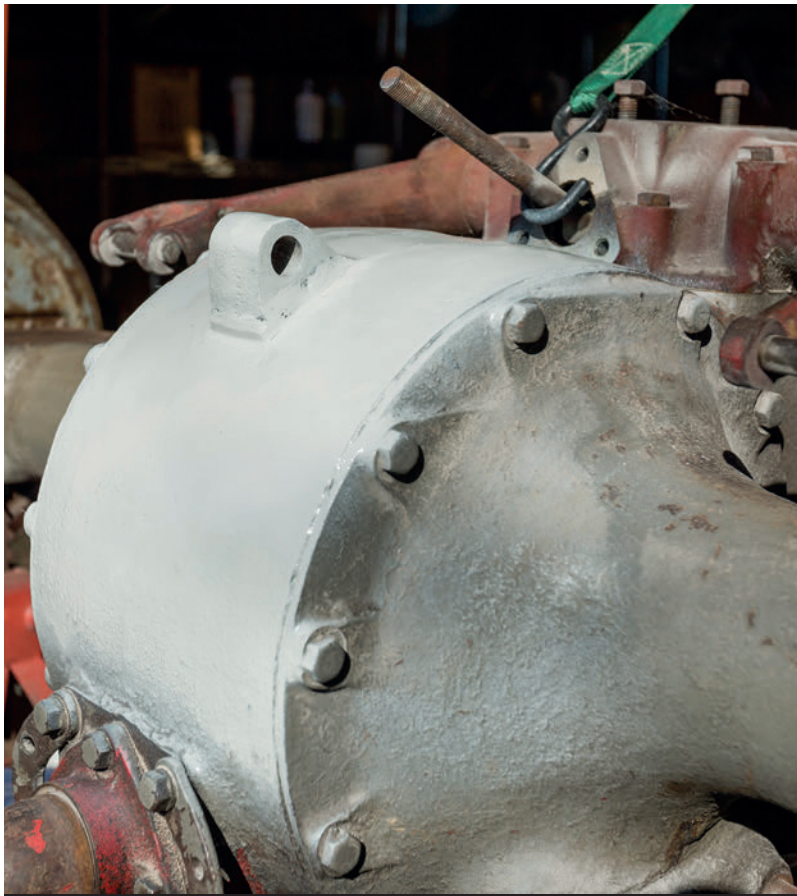
- Remove battery connections before welding on equipment.
- Clean out, pressure wash, steam clean, or degrease equipment before welding.
- Especially when working outdoors in dry conditions, soak areas around the welding site where combustion may occur and, after welding, soak again.
- Have a fire extinguisher, hose, portable pump tank, and fire blanket or welding blanket on site.
- Protect paint, glass, and plastics from hot sparks, goobers, or slag with a welding blanket.
- Protect shaft seals and hydraulic cylinder rod wiper seals from damage caused by hot goobers and slag.
- Be cautious about welding on closed containers or tanks as they may explode due to pressure from heat or from flammable contents.

Finishing Metal

Preparation for welding removes mill scale, grease, and paint, thus exposing fresh, bare metal to the atmosphere, an ideal condition for rapid corrosion. This is particularly true for most steels and for aluminum in a salt atmosphere. A protective finish will prevent corrosion and enhance the part's appearance. Protective coatings should go on promptly — ideally within a few hours — after welding (or final surface prep) so the metal does not have a chance to react with the atmosphere.

The most common protective finishes for welded products include:

- **PAINTING — FOR ALL METALS.** No specialized equipment is needed, but spray-painting may be best for complex shapes to reduce labor expense. Several coats may be needed to make the item weatherproof. A red Rust-Oleum primer and two more finish coats will provide at least 5 years of rust-free service outdoors.
- **POWDER COATING — FOR STEEL AND ALUMINUM.** Provides a durable, professional-looking surface with many colors and surface textures available. May be nearly as inexpensive as painting for complex shapes, as it is sprayed on. Holds up well outdoors.



After welding, metal should be protected with paint or some other type of coating.

Safety

Like many chores on the farm or ranch, welding can quickly become dangerous if basic safety precautions are ignored. Being aware of your surroundings is essential to safe welding. This includes not just during the welding process but also afterwards — be aware of where sparks fly and where molten slag lands. Many shops and barns have burned as a result of embers igniting between floorboards or a flake of hay catching on fire. Take the time to make your workspace safe.

Some welding processes have specific safety requirements. Here is a general list of important safety precautions for any welding process:

WORK SPACE SAFETY

- Always have an updated, well-marked fire extinguisher on site and in reach of the immediate work/welding area.
- The welding area should be clean and uncluttered, with no tripping hazards or puddles.
- Avoid welding on the floor if possible, with the work positioned on the table so that you can weld comfortably either sitting or standing.
- Besides taking other, more localized precautions for fume hazards while welding, provide adequate air ventilation for the entire space.
- Always work in a bright, well lit area; better visibility helps prevent accidents.
- The welding area must be free of flammable materials and all combustables must be stored in a fire-safe cabinet away from the immediate welding area.
- Keep compressed gas cylinders out of the stream of any sparks and properly secured/stored.

EQUIPMENT SAFETY

- Before using the equipment, inspect all hoses, cables, and electrical cords for damage.
- Never use defective or damaged equipment.
- Shut down equipment after use and keep it off when not in use.
- Do not change the polarity switch or other settings of a welder when it is under load (currently welding).
- Welding machines on AC power lines must be properly grounded with an accessible emergency shutoff switch.
- Place hot, discarded welding electrodes and rods in a safe place free of flammable material.

▲ A welding fume extractor removes potentially harmful vapors from the welding area without contaminating the weld.

▲ An auto-darkening helmet is absolutely necessary when welding. A leather jacket and gloves offer additional protection for the welder.

▲ Ear protection from excessive shop noise (grinding, hammering, etc.) can prevent damage that leads to permanent hearing loss.

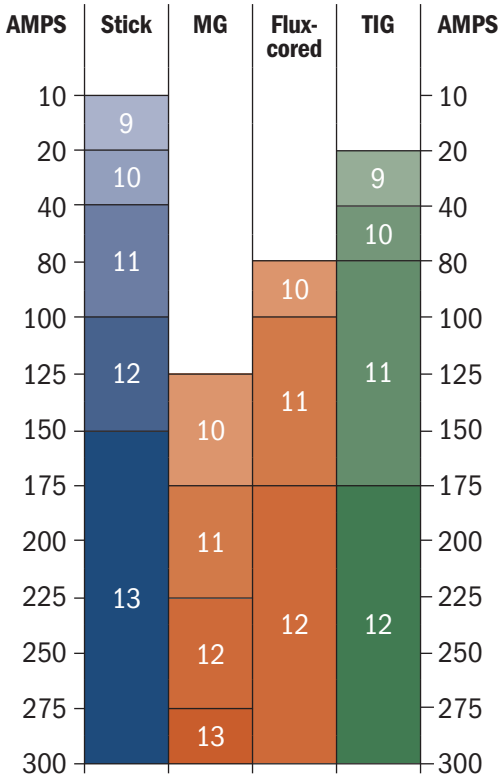
◄ Wearing safety glasses under your welding helmet provides ready eye protection during intermittent rounds of slag removal.

AUTO-DARKENING FACEPLATES

An electronic faceplate or lens is one of the most recent and important safety devices developed in the welding industry. These devices are designed to be clear, or nearly clear, then darken automatically the instant an arc is established. When purchasing a faceplate or lens, consider the time the lens takes to darken; 1/25,000 (0.00004) of a second or faster is recommended. Advantages of auto-darkening faceplates include:

- **The welder does not need to raise and lower his helmet when performing a series of welds; he can always see where he is with the helmet down.**
- **The beginner does not have to master holding his electrode steady when he drops his helmet. This permits beginners to perform better welds earlier in their training.**
- **Electronic faceplates offer continuous eye protection from infrared radiation coming off red-hot metal even when the faceplates are not in the darkened mode. It is just easier on the eyes, and the welder is less likely to incur eye injury from inadvertent arc strikes.**

Auto-darkening faceplates darken almost immediately as soon as the arc is established.



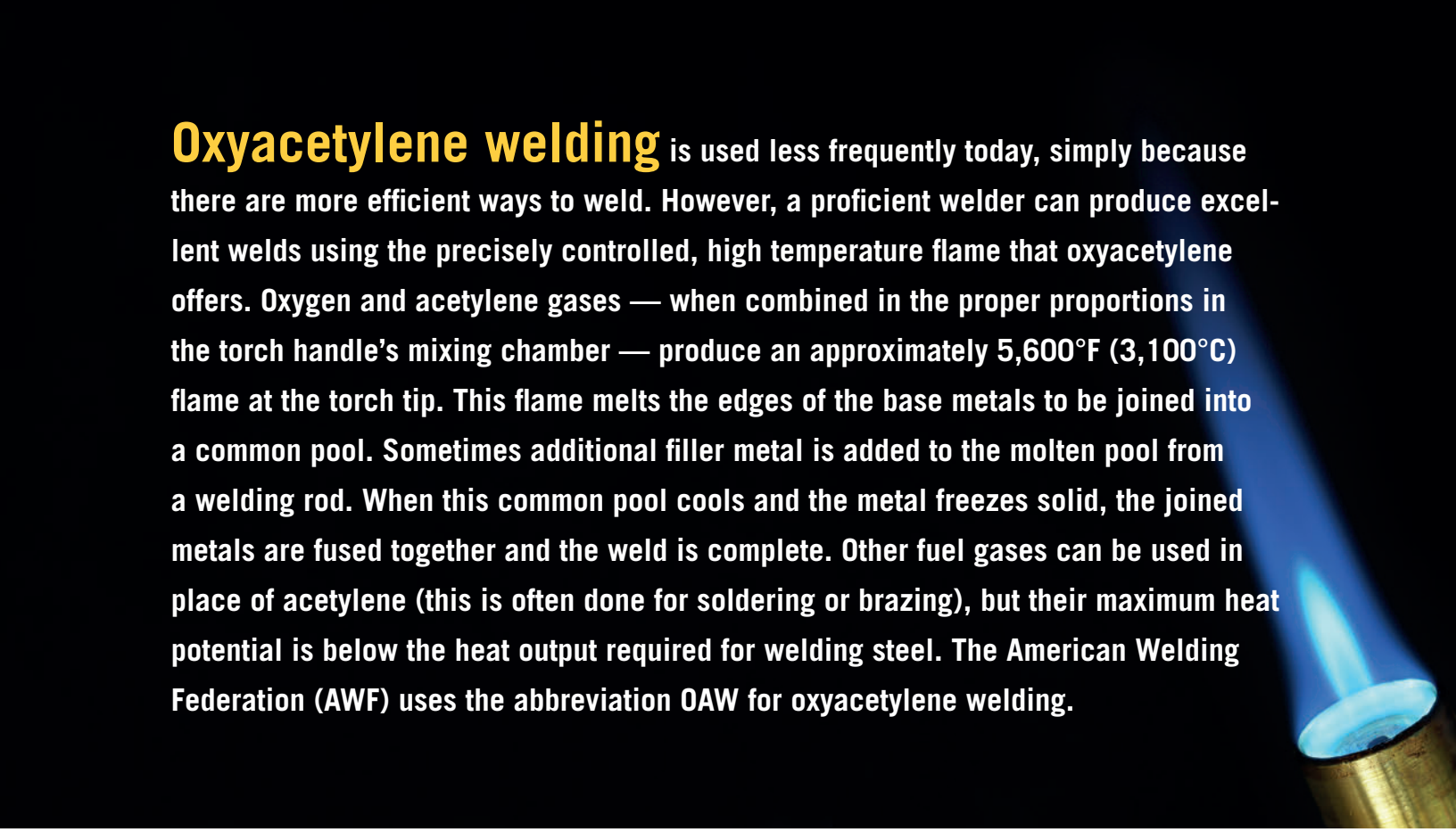
Recommended lens shade by amperage and welding process

PERSONAL SAFETY AND BASIC SAFETY EQUIPMENT

- Protect your eyes from sparks and radiation with a helmet or goggles with the appropriate shade lens for the process you are using. To avoid radition damage to the retinas, do not remove eyewear until the metal has cooled (is no longer red).
- Protect your skin from fire and harmful ultraviolet rays with protective clothing made of cotton, wool, specially treated canvas, and leather.
- Use protective screens to shield anybody in the welding area, including pets, from the harms of welding.
- Make sure anyone watching the welding process has the adequate eye protection and lens shade.
- Avoid welding vapors with proper ventilation, fume extractors, respirators, exhaust fans, and breathing apparatuses with an external fresh air source.
- Avoid welding heavy metals like zinc and cadmium, which produce toxic smoke.
- Wear leather garments and a welder's hat when welding overhead or vertically to protect yourself from sparks, falling slag, and hot metal.
- Wear high-top boots to better protect your feet.
- Never weld with pant cuffs, shirt pockets, or frayed material which can trap hot metal and sparks and easily burn.
- Make sure your gloves are dry, have no holes, and provide insulation from the work and heat of the welding process.
- Protect your ears from welding and grinding noise with earplugs or muffs.

THREE

OXYACETYLENE WELDING



Oxyacetylene welding is used less frequently today, simply because there are more efficient ways to weld. However, a proficient welder can produce excellent welds using the precisely controlled, high temperature flame that oxyacetylene offers. Oxygen and acetylene gases — when combined in the proper proportions in the torch handle's mixing chamber — produce an approximately 5,600°F (3,100°C) flame at the torch tip. This flame melts the edges of the base metals to be joined into a common pool. Sometimes additional filler metal is added to the molten pool from a welding rod. When this common pool cools and the metal freezes solid, the joined metals are fused together and the weld is complete. Other fuel gases can be used in place of acetylene (this is often done for soldering or brazing), but their maximum heat potential is below the heat output required for welding steel. The American Welding Federation (AWF) uses the abbreviation OAW for oxyacetylene welding.

When to Use OAW

If you have many different types of projects or repairs, OAW processes work well, particularly if you are not near an electrical power source. Unlike other welding processes, OAW does not require electrical power. Use it for welding thin sheet, small rod, thin strips, tubing, and small-diameter pipe.

ADVANTAGES

- Low cost
- Readily portable
- Excellent control of heat input and puddle viscosity
- No external power required
- Good control of bead size and shape
- Fuel mixture is hot enough to melt steel

DISADVANTAGES

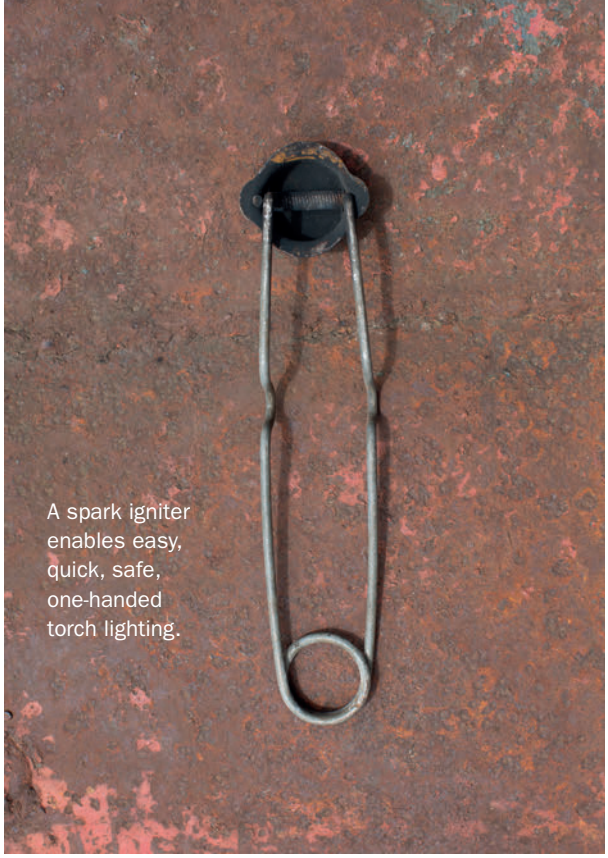
- Not economical to weld thick pieces of metal, compared with other processes
- Slowest of the welding processes

METALS THE OAW PROCESS CAN READILY WELD

- Copper
- Bronze
- Lead
- Low-alloy steels
- Wrought iron
- Cast steel

USING OAW TO WELD ALUMINUM AND STAINLESS STEEL

Aluminum and stainless steel usually are not welded using the OAW process. Aluminum, for example, does not change color prior to melting, so it requires extra welder skill to control heat input. It also lacks strength at high temperatures. Exposed aluminum has a very thin oxide layer that requires the use of flux, and the oxide surface does not let the welder see a wet-looking molten weld pool. However, both aluminum and stainless steel may be welded with OAW, provided one or more of the following steps are taken: preheating the metal, post-heating, using fluxes, or using special welding techniques.



A spark igniter enables easy, quick, safe, one-handed torch lighting.

Use pliers for moving hot metal.

Basic Safety Procedures for OAW

All construction projects require a group of safe practices, and welding is no exception. Chapter 2 covered general safety measures for welding, but there are additional safety practices and equipment that are specific to OAW processes.

ESSENTIAL PIECES OF SAFETY EQUIPMENT

- Nonsynthetic fabric (cotton or wool) long-sleeved shirt buttoned to the top to prevent sparks from entering
- Tinted welding goggles with minimum of number 5 shade lenses
- Leather gloves
- Spark igniter, for lighting welding torch
- Pliers for moving hot metal

VENTILATION

Make sure the welding area is well ventilated to draw the weld fumes away from the welder. Many fumes from the welding process are poisonous and must be avoided. Welding fumes from cadmium plating, galvanized sheet metal, lead, brass (which contains zinc), and many fluxes (especially those containing fluorine) are poisonous. They can have both immediate and long-term adverse health effects.

Welding supply companies, welding equipment manufacturers, and materials suppliers will provide MSDSs (Material Safety Data Sheets) on request. Often they are also available for downloading from manufacturers' websites. An MSDS details the hazards of a material or equipment and explains how to deal with them safely. These documents are particularly helpful in understanding the fume hazards of fluxes, solders, and brazing materials.

There are a variety of ways to protect the respiratory system while welding, from disposable respirators and fans to filtered fume extractors and air supply masks with air being pumped in from

an external source. It is extremely important to understand the hazards of breathing in welding fumes, and to find out what precautions need to be taken for each specific process you're using and project you're working on.

DO NOT WELD SEALED CYLINDERS OR OTHER CONTAINERS

Never weld on a sealed container regardless of its size. Even if the vessel is clean and empty, penetration of the shell could release hot gases from the interior. They could also drive the torch flame back towards the welder. If the cylinder is empty and contains no residual vapors, vent it to atmosphere by opening a valve, hatch, or bung, or by carefully drilling a hole.

An even more dangerous situation results when the cylinder contains residual flammable vapors whether it is vented to atmosphere or not. Welding on such a cylinder will almost certainly result in an explosion. Clean or purge the cylinder with an inert gas, then have it checked for explosive vapors by a qualified person. Vent it to the atmosphere and begin welding. In some cases, filling the vessel with water or other liquid and welding below the liquid is acceptable, but this is an area for experienced, knowledgeable welders.

SAFETY RULES FOR USING COMPRESSED GAS CYLINDERS

- **NEVER use oxygen in place of compressed air.**
- **NEVER use oxygen for starting engines or cleaning clothing.**
- **Store and use acetylene and propane cylinders with the valve end up, and separate them from oxygen cylinders.**
- **Secure cylinders to prevent them from being knocked over in use.**
- **Use valve protection caps on cylinders while moving them.**
- **Use a striker to light an oxyfuel torch. Never use a match or cigarette lighter because these can cause a large fire or explosion with the potential power of a half-stick of dynamite.**
- **NEVER leave a lighted torch unattended.**
- **When a cylinder is empty, close the valve and mark it *EMPTY (MT)*.**
- **DO NOT attempt repair of cylinder valves or regulators; send them to a qualified repair shop.**
- **NEVER use compressed gas cylinders as rollers.**
- **NEVER attempt welding on a compressed gas cylinder.**
- **Keep power and welding cables away from compressed gas cylinders.**
- **Prevent sparks from falling on other people or combustible materials or falling through cracks in the floor or on OAW hoses.**
- **On old-style acetylene cylinders with a removable valve wrench, always leave the wrench in place when using the equipment so that it can be shut off quickly in an emergency.**
- **When transporting compressed-gas cylinders by vehicle, have the cylinder caps in place and secure the cylinders so they will not move around as the vehicle starts and stops. Never transport cylinders with the regulators in place.**
- **NEVER carry compressed gas cylinders inside a car or car trunk.**

A basic OAW setup includes cylinders of oxygen and acetylene, regulators for the tanks, hoses, and a welding torch.

Types of Equipment for OAW

For the farm or ranch an OAW setup is invaluable. It can be used for cutting, heating, and welding. Additionally, OAW equipment is available in a variety of sizes, including portable OAW setups which can be carried to the field for repair work.

COMPRESSED GAS CYLINDERS

OAW utilizes cylinders of compressed oxygen and acetylene. It's very important to be able to tell oxygen cylinders apart from acetylene cylinders, to avoid dangerous accidents.

OXYGEN CYLINDERS

Oxygen cylinders are seamless vessels of special high-strength alloy steel. They are made from a single billet by a draw-forming process and they contain no welds. Frequently, oxygen cylinders are painted green or have a green band, but the only sure way to determine the contents of a compressed gas cylinder is to *read* the adhesive label on it. This label is required by law and should not be removed. Do not go by the tank's color, as there is no color code. Unlike civilian industry, however, the U.S. armed forces *do* color-code their cylinders.

ACETYLENE CYLINDERS

Unlike oxygen cylinders, acetylene cylinders are fabricated and contain welds. Like most other fuel-gas handling equipment, acetylene has a notch or groove cut in the middle of the edges of the hexagonal faces of the swivel nut that connects the tank to the regulator. This is a flag for a left-handed thread.

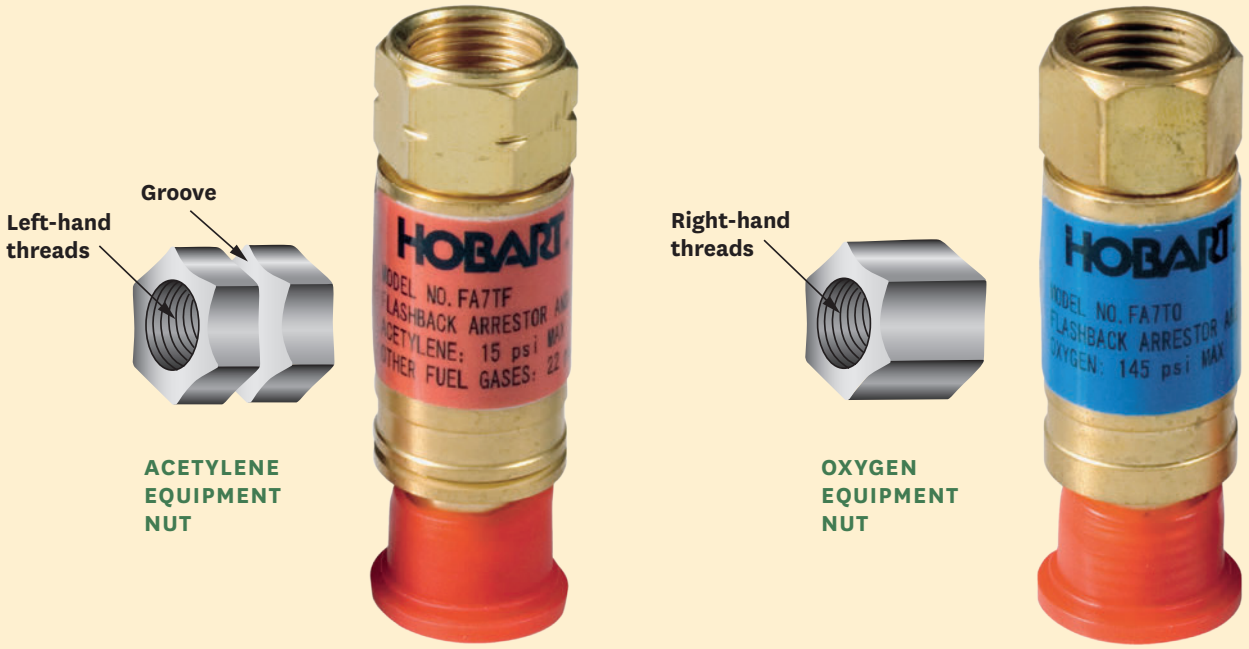
Acetylene will form explosive mixtures with air at *all* concentrations between 2.5 and 80 percent. This is the widest range of any common gas and almost ensures an explosion if leaking gas is ignited. At 70°F (21°C), the acetylene should show 225 psi (15.5 bar), and the oxygen should show 2,250 psi (155 bar). Note that these pressures will fluctuate with ambient temperature.

Transporting cylinders. If an acetylene cylinder has been incorrectly transported on its side, the welder should not use it right away. The acetylene gas and the acetone in which it is dissolved may become mixed in the area just below the valve, resulting in both gaseous acetylene and liquid acetone at the top of the cylinder. This is where acetylene exits the cylinder and goes through the valve to enter the regulator. Both acetylene gas and liquid acetone will be drawn into the regulator, possibly ruining the rubber components of the regulator and torch and creating a safety hazard. The weld metallurgy may also be contaminated.

To use the cylinder, stand it upright and wait at least 30 minutes before connecting and using the cylinder to allow the liquid phase of the acetone to separate from the acetylene gas in the upper portion of the cylinder.

Comparing Connector Nuts

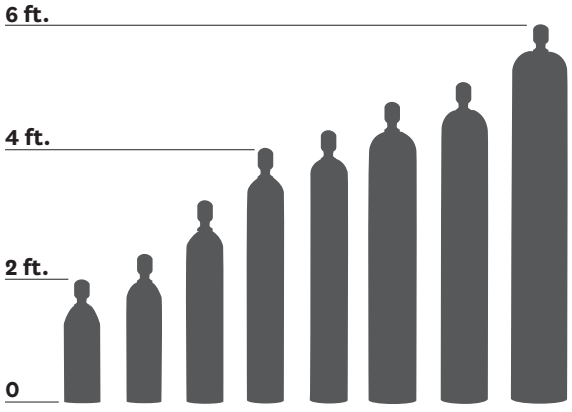
This illustration compares connector nuts for acetylene and oxygen equipment. Being aware of this difference will prevent possible damage to soft brass threads, and will keep you from connecting to the wrong tank.



Common Cylinder Sizes

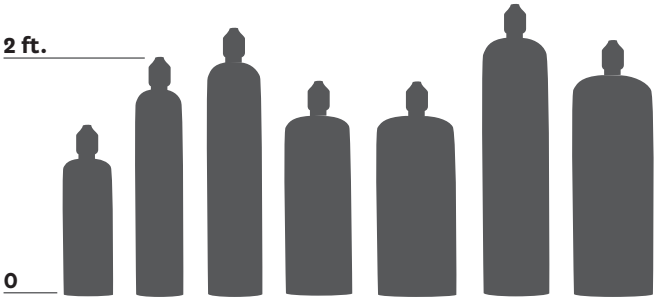
A 55 cubic foot (1557 liter) oxygen cylinder would last under 2 hours cutting ⅛-inch steel plate. For the larger cylinders, their size and weight can be major drawbacks. In general, the midsize cylinders offer the best compromise of economy and convenience.

OXYGEN CYLINDER SIZES



ft^3	40	55	80	110	150	250	300	400
Empty Weight (lbs.)	23	30	42	55	59	115	135	190

ACETYLENE CYLINDER SIZES



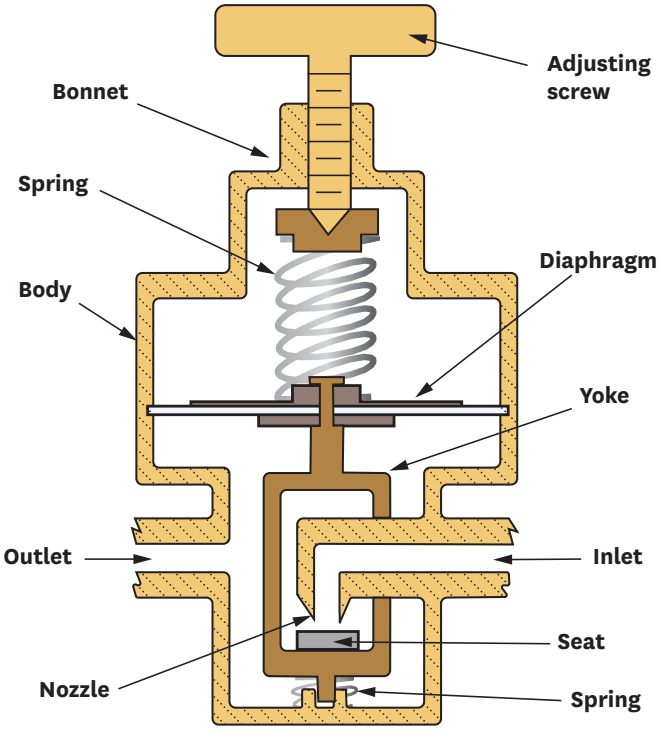
ft^3	75	100	145	210	225	250	390
Empty Weight (lbs.)	44	55	75	101	107	117	171

REGULATORS

Regulators reduce the pressures of welding gases from the very high cylinder pressures to the low pressures needed by the torch to function properly. Also, as the cylinder pressure falls with gas consumption, the regulator maintains the constant pressure needed by the torch, even though the cylinder supply pressure drops greatly. For example, an oxygen cylinder may contain oxygen at 2,250 psi (155 bar) and the torch requires about 6 psi (0.4 bar) to operate. Similarly, a full acetylene tank may contain gas at 225 psi (15.5 bar) and the torch needs fuel gas at 6 psi (0.4 bar).

There are single-stage and two-stage regulators available. The two-stage regulator's advantage is that a higher volume of gas may be withdrawn from the cylinder with less pressure fluctuation than produced by a single-stage regulator. Two-stage regulators working together in series maintain a very constant torch pressure over wide cylinder pressure changes. The disadvantage is that it is a more expensive piece of equipment than a single stage regulator, and is only needed when large gas volumes are necessary, as with multiple stations or when using a rosebud tip (which is for heating metal and consumes large quantities of gas).

WARNING: Acetylene regulators should never be adjusted to over 15 psi (1 bar), as this can cause an explosion.



A single-stage, nozzle-type pressure regulator helps maintain constant torch pressure.

An oxygen tank regulator features gauges for measuring both the amount of oxygen flowing from the tank through the torch (working pressure), and the amount of oxygen stored in the cylinder (tank pressure).

TORCHES AND TIPS

Shown below is the most common oxyacetylene torch design. Other designs are available, as well. Some have very small flame for jewelry and instrument work, while others take no accessories and are much lighter in weight than standard torch designs to reduce operator fatigue. Some torch handles can accommodate cutting heads.

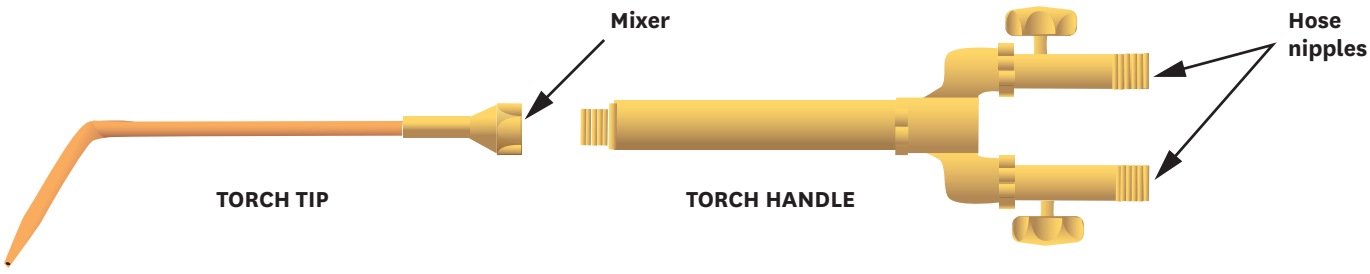
It is important to match the size of the flame, which is controlled by the torch tip, and the resulting volume of gas to the thickness of the metal in the weld. Too much flame can damage the base metal around the weld. Too little flame may produce inadequate heat to melt metal for full penetration.

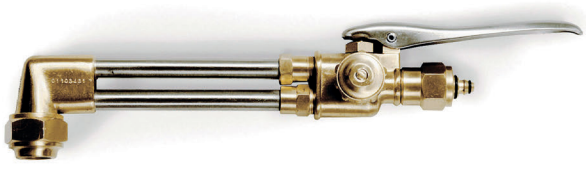
TORCH TIP SIZES

The size torch tip you use will depend on how thick of a piece of metal you are going to weld. Unfortunately, there is no industry standard for torch tip sizing, For example, one company's #3 tip can be a considerably different size, with a bigger or smaller orifice than another company's #3 tip.

Most welding manufacturers provide information booklets to cross-reference their tip sizes to drill sizes. If that information is not available, you can match the right size tip to the correct material thickness, using a tip cleaner. Find the round file that fits snugly into the orifice of the tip. The drill size of that file will be listed on the body of the tip cleaner cover. You can then reference that number accordingly, using the table on page 65.

OXYACETYLENE TORCH AND TIP





Cutting head attachment

Oxyacetylene torch handle

Matching Welding Tip Size to Weld Material Thickness

Material Thickness Range (in.)	Filler Rod Diameter (in.)	Tip Drill Size	Orifice Size (in.)	Approximate Flame Cone Length (in.)
1/32–1/16	1/16	69	0.029	3/16
1/16–1/8	3/32	64	0.036	1/4
1/8–3/16	1/8	57	0.043	5/16
3/16–5/16	1/8	55	0.052	3/8
5/16–7/16	5/32	52	0.064	7/16
7/16–1/2	3/16	49	0.073	1/2
1/2–3/4	3/16	45	0.082	1/2
3/4–1	1/4	42	0.094	9/16
Over 1	1/4	36	0.107	5/8
Heavy Duty	1/4	28	0.140	3/4

CLEANING TORCH TIPS

When sparks from the weld puddle deposit carbon inside the nozzle and on the tip face, they act as spark plugs and cause premature ignition of the gas mixture. Torch tips should be cleaned at the start of each day's welding and whenever flashback (see page 66) occurs, the flame splits, or when the sharp inner cone of the flame no longer exists. To clean a torch tip, select the largest torch tip cleaning wire file that fits easily into the nozzle and use the serrated file to remove any foreign material.

Be careful not to bend the tip cleaning file into the tip, which can cause the file to break inside the tip; if this happens, the file is nearly impossible to remove. Also be sure not to enlarge the existing hole. The goal is to clean the hole, not enlarge it.

After cleaning inside the tip, touch up the face of the tip with a file or emery cloth to remove any adhering debris. Then, use compressed air or oxygen to blow out the tip. Never use a twist drill to clean the tip; it will distort the mouth of the tip.

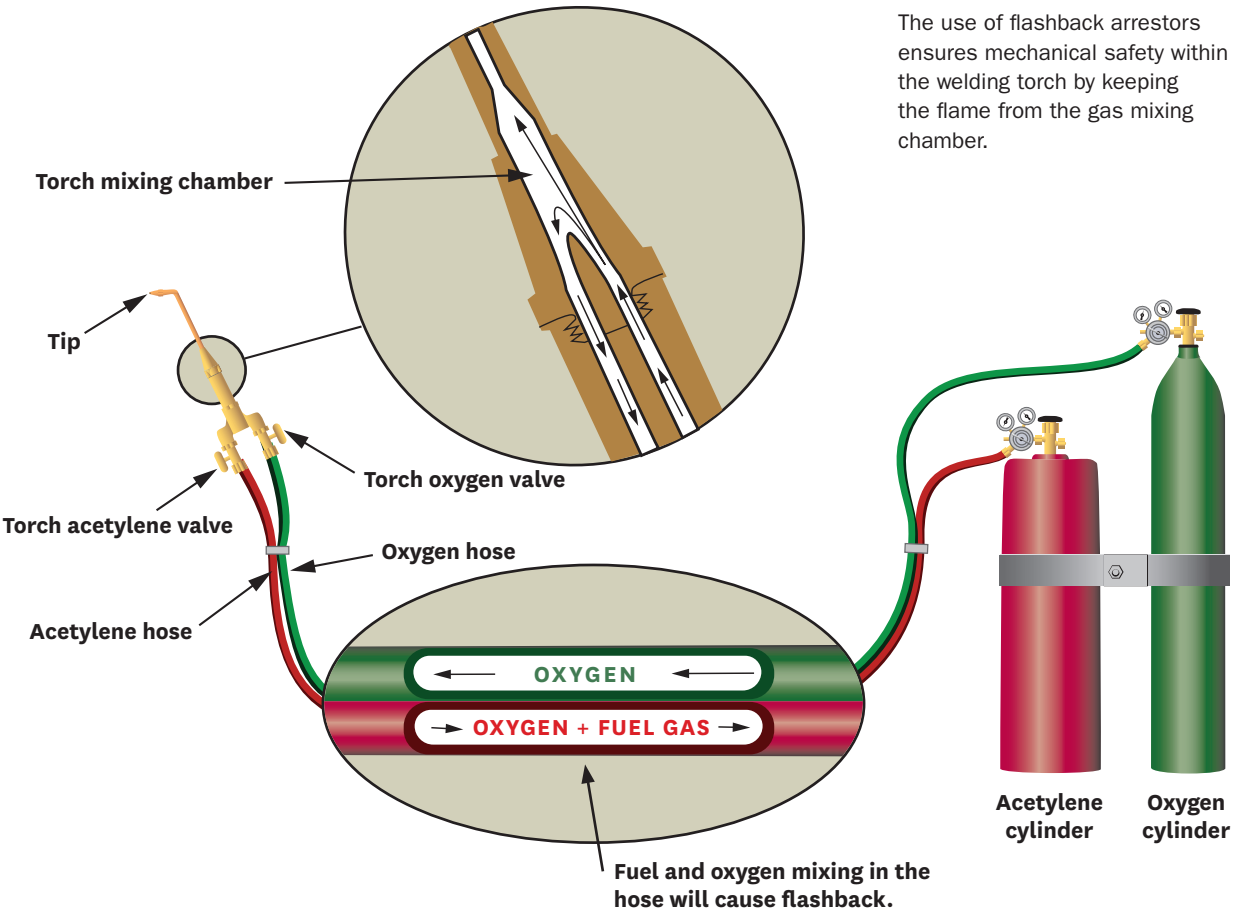
A torch tip cleaning kit will contain a variety of round files in different sizes, for cleaning orifices, and a slag removal tool. The size of each file is listed on the back of the kit, which is helpful in identifying tip size.

PREVENTING FLASHBACK AND BACKFIRE

Flashback occurs when a mixture of fuel and oxygen burns inside the mixing chamber in the torch handle and reaches the hoses to the regulators or cylinders. Such burning in the hoses is extremely dangerous and will lead to serious injury. This can happen through operator carelessness (like turning on both the acetylene and the oxygen with the torch tip blocked) or through regulator failure. The result is that an explosive mixture of acetylene and oxygen is forced back toward the cylinders. When the torch is lit, this explosive mixture will ignite.

Flashback is easily prevented by the installation of flashback arrestors, which consist of both a check valve and a flame arrestor; this redundancy in the system offers an extra measure of safety. These devices are about the diameter of the gas hoses and about 1¾ inches long. Some newer torch designs incorporate check valves and flashback arrestors into the torch handle itself. Some arrestors fit between the regulator and the hose. The best arrestors include a thermally activated, spring-loaded shutoff valve that closes when it senses a fire.

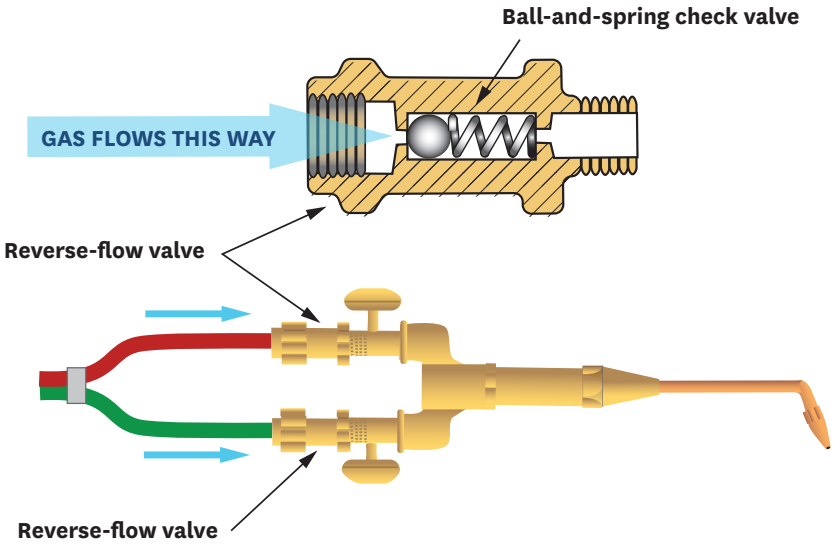
A backfire is a small explosion of the flame at the torch tip. The primary hazard associated with a backfire is that the detonation from the tip may blow molten weld metal 5 to 10 feet from the weld and injury someone. Also, a series of repeated, sustained backfires, which can sound like a machine gun, may overheat the tip or torch, permanently damaging it.



The use of flashback arrestors ensures mechanical safety within the welding torch by keeping the flame from the gas mixing chamber.

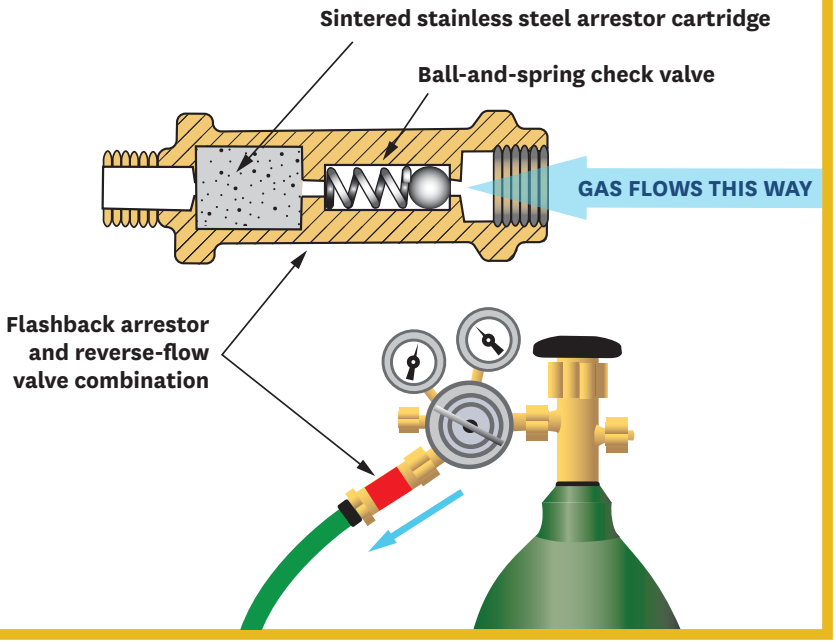
The most frequent cause of backfire is pre-ignition of the mixed acetylene and oxygen. Here are the most common causes of pre-ignition and their solutions:

- **The mixed welding gases are flowing out through the tip more slowly than the flame front burns and the flame front ignites the gas in the tip and/or mixing chamber, causing a pop. Solution: Slightly increase both the oxygen and acetylene pressures. If this results in too large a flame for the job, reduce the torch tip size.**
- **The tip may be overheated from being held too close to the weld or from working in a confined area, like a corner. Solution: Let the tip cool off and try again, holding the tip farther from the weld pool.**
- **Carbon deposits or metal particles inside the tip act like spark plugs, prematurely igniting the mixed gases. Solution: Let the tip cool, then clean it thoroughly with your tip cleaning kit.**



CROSS SECTION OF REVERSE-FLOW CHECK VALVE FLASHBACK ARRESTOR

The thermally activated ball and spring mechanism stops the oxyacetylene mixture from dangerously flashing back into the hose, regulators, and tanks.



Selecting the Filler Metal (Welding Rod)

For the oxyacetylene torch, there are a number of different types of filler material for fusing different types of metal. For this section we will specifically discuss the filler metal for welding steel. Other options for brazing and braze welding will be dicussed in chapter 7.

Oxyacetylene welding filler material comes in different sized copper-coated steel rods. They usually come in approximately 36-inch lengths and vary from 1⁄16 to 3⁄8 inch in diameter. The right diameter is determined by the thickness of the base metal to be welded and the size of the gap that needs to be filled.

Usually the filler metal is a close match to the base metal, and will sometimes have deoxidizers added, which will improve the weld more than just a base metal match. The welding rods are identified by the AWS classification system (see the table below). The prefix "R" just stands for "rod," and the following number is the rod's tensile strength, in thousands of pounds per square inch. An R45 rod is the most widely used, general-purpose rod for welding low-carbon steel, while R100 is used specifically for stronger, alloy steels.

The filler metal of OAW rods should closely match the base metal you'll be welding.

Oxyacetylene Steel Welding Rods

AWS Classification	Minimum Tensile Strength (ksi)	Elongation in 1 inch (minimum %)*
R45	45	22
R60	60	20
R65	65	16
R100	100	14

***Refers to the amount the rod material can be bent, stretched, or compressed before it fails.**

Before setting up to weld, remove all surface dirt, scale, oxide, grease, and paint from the area to be welded, including the surfaces adjacent to and underneath the area to be welded.

With the tank valves closed, back out the pressure-adjusting screws on the regulators. When opening the tank valves, stand to the side or behind the tank in case the regulator malfunctions and explodes.

Setting Up the Equipment for OAW

Learning to set up OAW equipment in the proper order is essential for personal safety and to prevent damage to gas regulators. Many welders include a "cheat sheet" that is taped to their tanks and outlines both the operating procedure and common working pressure regulator settings for a variety of applications.

1 **Put on your welding safety equipment.** At a minimum, you should have tinted safety goggles (or tinted face shield), a cotton or wool shirt and pants, high-top safety shoes, and welding gloves.

2 **Remove empty cylinders and secure new ones.** Make sure the valves on previously used or empty cylinders are fully closed and their valve protection covers are securely screwed in place. Remove the empty cylinders from the work area and secure them against tipping during the wait for a refill shipment. Secure the newly replaced or full cylinders to a welding cart, building column, or other solid anchor to prevent the cylinders from tipping over during storage or use.

3 **"Crack" the valves.** Confirm that the regulators are off and the gas openings are pointing away from anyone. Briefly open each cylinder valve to the atmosphere, then close the valve quickly to purge the valve; this is known as "cracking" a valve. Cracking serves to blow out dust and grit from the valve port and to prevent debris from entering the regulators and torch.

4 **Clean the fittings.** Use a clean, oil-free cloth to wipe off the cylinder valve-to-regulator fittings on both cylinders, removing dirt and grit from the fittings' connection faces and from the fittings' threads. Do the same to both regulators' threads and faces.

WARNING: Never use oil on high-pressure gas fittings. Oxygen at high pressures can accelerate combustion of oil into an explosion.

5 Install flashback arrestors. Make sure flashback arrestors are installed on the torch or the regulators.

6 Connect each regulator to its respective cylinder. Snug-up the connections with a wrench. Remember, all acetylene fittings always thread counter-clockwise, all oxygen fittings thread clockwise.

7 Loosen screws. Before opening the valves, make sure that both the oxygen and acetylene regulator pressure adjustment screws are unscrewed and loose.

8 Stand so the cylinders are between you and the regulators. Standing so that the cylinders are between you and the regulators offers some protection should the regulator fail and the housing and gauges explode. SLOWLY open the oxygen cylinder valve until it hits the upper valve stop and will turn no further. Also standing so the cylinders are between you and the regulator, open the acetylene cylinder valve gradually and not more than 1½ turns. If there is an old-style removable wrench on the acetylene cylinder, keep it on the valve in case you must close it in an emergency.

9 Purge each torch hose of air separately. Open the oxygen valve on the torch about three-quarters of a turn, then screw in the pressure control screw on the oxygen regulator to your initial pressure setting — about 6 psi (0.4 bar). After several seconds, close the torch valve. Do the same for the acetylene hose. You do this for two reasons: (1) to make sure you are lighting the torch on just oxygen and acetylene, not air, and (2) to set the regulators for the correct pressure while the gas is flowing through them.

WARNING: Never adjust the acetylene regulator pressure above 15 psi (1 bar) as an explosive disassociation of the acetylene could occur.

10 Recheck the low-pressure gauge pressures. You want to make sure the working pressures are not rising. If the working pressure rises, it means the regulator is leaking. Immediately shut down the cylinders at the cylinder vales. Continued leaking could lead to a regulator diaphragm rupture and a serious accident. Replace and repair the defective regulator.

11 Check for leaks. Test the system for leaks at the cylinder-to-regulator fittings and all hose fittings with special leak detection solutions; bubbles indicate leaks. Soapy water in a spray bottle will also work in a pinch to detect a leak.

TYPES OF FLAMES

There are three types of flames that different ratios of oxygen and acetylene can produce.

- **Oxidizing flames result when there is an excess of oxygen over acetylene. This flame will change the metallurgy of the weld pool metal by lowering the carbon content as it is converted to carbon dioxide.**
- **Neutral flames result when there is just enough oxygen to burn all the acetylene present. This flame is most frequently used in welding common materials.**
- **Carburizing flames result when there is an excess of acetylene gas over the amount that can be burned by the oxygen present. The opposite of an oxidizing flame, it adds carbon to the weld pool and can change its metallurgy, usually adversely.**

An oxidizing flame is significantly hotter than the other two flames but is less useful because it introduces more contaminants into the weld pool. An oxidizing flame is often used in braze welding or in fusion welding of heavy, thick parts with brass or bronze rod. In these applications, we are not concerned with weld pool contamination. An oxidizing flame is required for oxygen-fuel cutting.

Lighting and Adjusting the Torch

Using a striker and adjusting small valve knobs with thick gloves may feel awkward and clumsy at first. With enough practice, you will be able to safely and efficiently light the torch and adjust the flame to neutral as if it were second nature. Here are the steps:

1 Attach a tip. Select the correct tip size for the thickness of the metal being welded.

2 Light with a spark igniter. Open the acetylene valve no more than 1/16-turn and hold a spark igniter at an angle to the torch tip to ignite the gas coming out of the tip. A smoky orange flame will be the result.

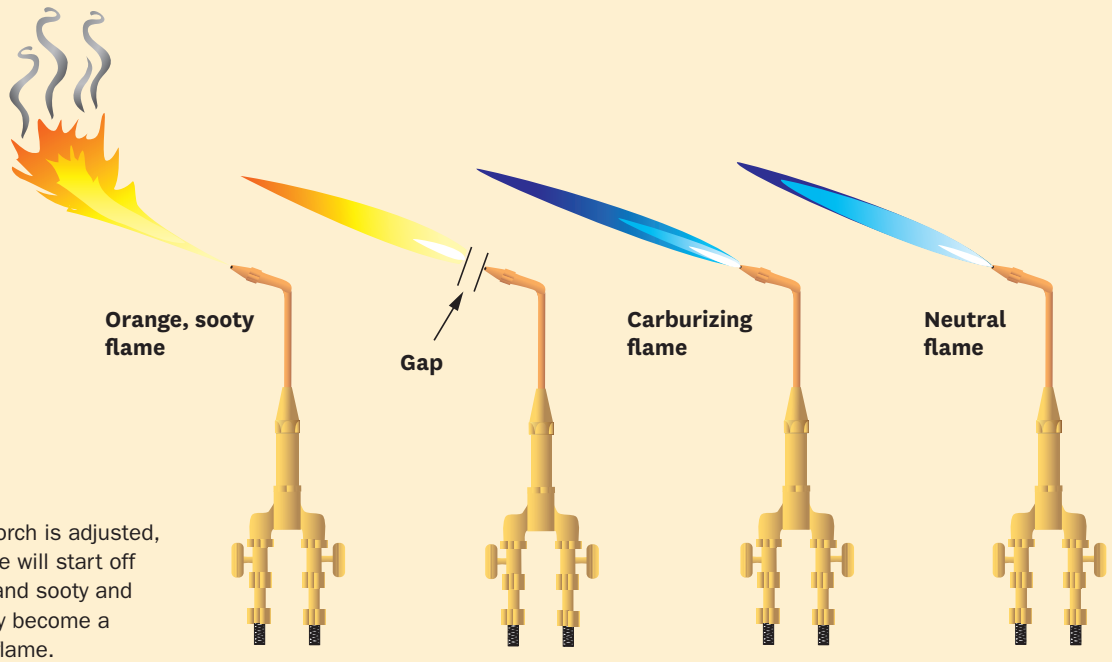
3 Adjust the acetylene valve. Continue to open the acetylene valve until the flame stops smoking (releasing soot). Another way to judge the proper amount of acetylene is to open the acetylene valve until the flame jumps away from the torch tip, leaving about a 1/16-inch gap. Then, close the valve until the flame touches the torch tip.

4 Open the oxygen valve slowly. As the oxygen is increased, the orange acetylene flame turns purple, and a smaller, white inner cone will begin to form. With the further addition of oxygen, the inner cone goes from having ragged edges, to sharp, clearly defined edges. The flame is now neutral, and adding oxygen will make an oxidizing flame.

If you need a larger flame while keeping the same tip size, you can increase the acetylene and the oxygen to keep the inner cone's edges sharp. This process of increasing the acetylene, then the oxygen is usually done in several cycles before you achieve the maximum flame available from a given tip.

NOTE: Adjusting the flame below the minimum flow rate for the tip orifice permits the flame to ignite inside the nozzle. This is a backfire and makes a popping sound. If you need a smaller flame, use a smaller torch tip. **See Preventing Flashback and Backfire on page 66.**

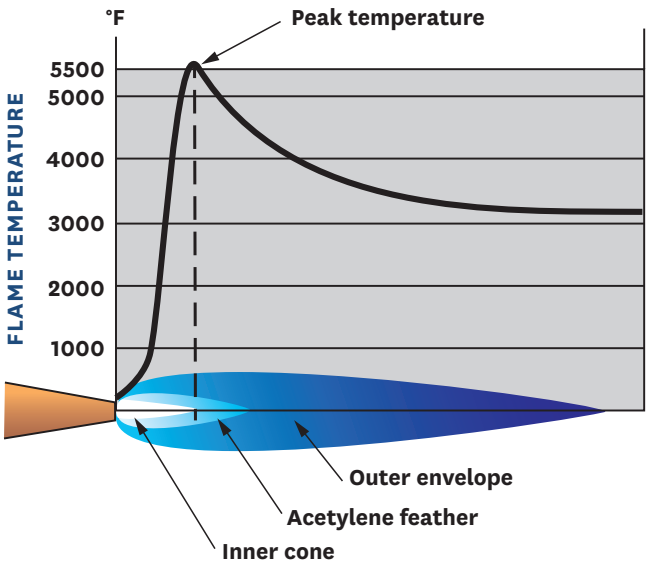
Adjusting the Flame



As the torch is adjusted, the flame will start off orange and sooty and gradually become a neutral flame.

FLAME TEMPERATURES

The inner cone is where the optimum mixture of oxygen and acetylene burn, and the tip of the inner cone is the hottest part of the flame. The outer envelope is where any unburned acetylene burns with oxygen from the atmosphere for combustion. A neutral flame occurs when enough oxygen is present in the flame to be burning all of the acetylene gas and is used for most welding processes.



LIGHTING A MULTI-FLAME (ROSEBUD) TIP

This type of tip produces a large flame for heating metal prior to welding, bending, or brazing or for post-heating to reduce stresses after welding. Follow these steps to establish a multi-flame tip:

1 Set the acetylene pressure at or just below 15 psi (1 bar), and set the oxygen pressure at 30 psi (2 bar).

2 Open the acetylene torch valve far enough to light the acetylene flame, and ignite the flame.

3 Open the acetylene valve until you have a full flow of gas.

4 Open the oxygen torch valve and adjust the flame to slightly carburizing.

At this point, you may use the multi-flame (rosebud) to heat materials, but keep the sharp inner cone flame away from the material and only touch the carburizing flame to the material being heated. A heat-sensing device, such as a pyrometer or temperature-sensing stick, can be applied to the material to indicate the temperature of the material being heated and to keep temperatures consistent from one welding pass to the next (known as the interpass).

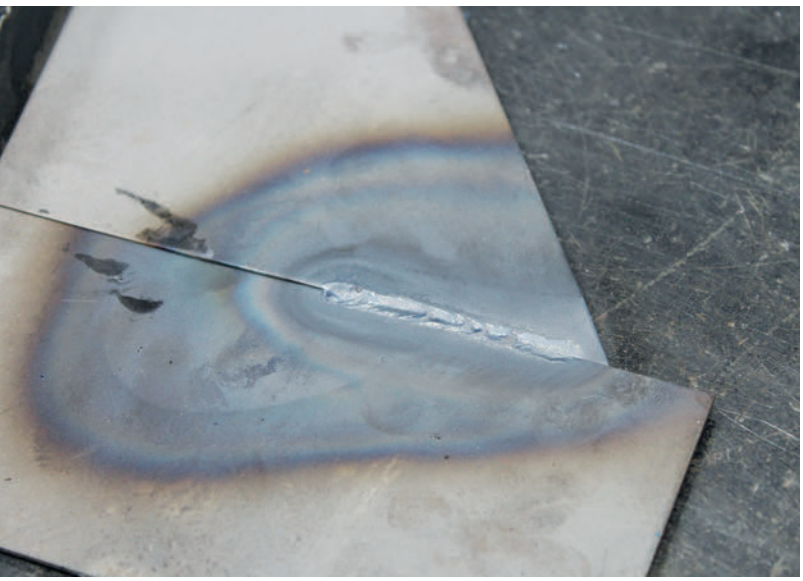
A rosebud tip is often used to preheat materials prior to welding and post-heat (if required) after welding.

Producing a Good Weld Bead

Producing a good weld bead is a combination of four main factors: the distance between the torch tip and the work, the angle at which you hold the torch, your speed when moving the torch along the weld area, and the heat produced by the torch. Getting everything right takes practice, so always test your technique on scrap metal first.

1 Create a puddle at the start of the bead. Keep the tip steady until a puddle begins to form. Begin making a circular motion with the torch, slowly moving the torch tip in the direction of the bead. Keep the distance to the work and the speed of your movements consistent.

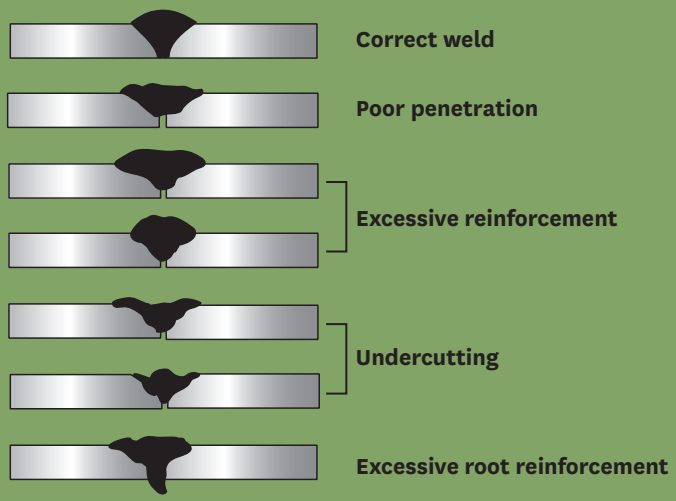
2 Now try it with a filler rod. The goal is to intermittently dip the end of the rod into the puddle to add material to the weld (the molten puddle melts the filler rod). Dip the end of the rod into the puddle, opposite the torch tip, while making a circular motion with the torch. This helps to blend the filler material into the weld. Withdraw the rod from the puddle, but keep it close to the end of the torch to keep it preheated. Don't directly heat the end of the rod with the torch.



3 The finished bead should be even throughout its length. The ripples created by the circular motion of the torch tip should be consistent.

Judging Welds

Many variables go into producing a good weld with full penetration and a nice, even bead. Below is a weld bead comparison chart showing a correct weld in comparison to a number of incorrect welds that run the troubleshooting spectrum.



SHEET METAL REPAIR

This old tractor fender was full of holes which needed to be filled to return it to its original glory. We used a hammer and dolly to remove the major dents and we prepped the area around the holes with a wire brush. Because the sheet metal on this old fender was so thin, we opted for oxyacetylene welding, since it offers easy puddle and heat control.

1

Choose your tip and rod. Although you can use the same oxy-acetylene setup as for cutting, you'll need to switch from a cutting tip to a welding tip on the torch. Additionally you'll need a mild steel filler rod; RG 45 is a good general purpose choice.

2

Use your torch to heat the metal around the hole you wish to fill, then follow the torch with the filler rod and push the weld puddle from the edge.

3

Work your way around the hole and if the weld puddle becomes too hot, simply allow it to cool for a few seconds.

4

With the holes filled, inspect the sheet metal for distortion. Use a hammer, dolly, and light grinding to smooth out the surface.

5

The repaired fender is ready to be sandblasted, painted, and reinstalled on the tractor.

Shutting Down the Equipment

Make a habit of shutting down the equipment at the end of the day and when it's not in use. Following the steps below will further ensure shop safety and help preserve the equipment.

1 **Turn off oxygen first.** Turn off the oxygen with the torch handle valve, then turn off the acetylene with the torch handle valve. Always turn off the oxygen valve first; turning off the acetylene first can cause a flashback.

2 **Close the regulator valves.** Turn off the oxygen and acetylene cylinder valves at the regulators.

3 **Bleed the hoses.** Open and close the oxygen and acetylene valves separately on the torch handle to bleed the remaining gas in the hoses and regulator into the atmosphere. Verify that both the high-pressure and low-pressure gauges on both regulators indicate zero.

4 **Loosen the regulator screws.** Unscrew the regulator pressure adjustment screws on both cylinders in preparation for the next time the equipment is used. The regulator screws should be loose but not about to fall from their threads.

STRAIGHTENING BENT PARTS

This three-point hitch side link can be straightened with an oxyacetylene torch, a truck hitch, and some patience.

1

Slide the bent link into the hitch and heat until cherry red. Heat the entire length of the bend.

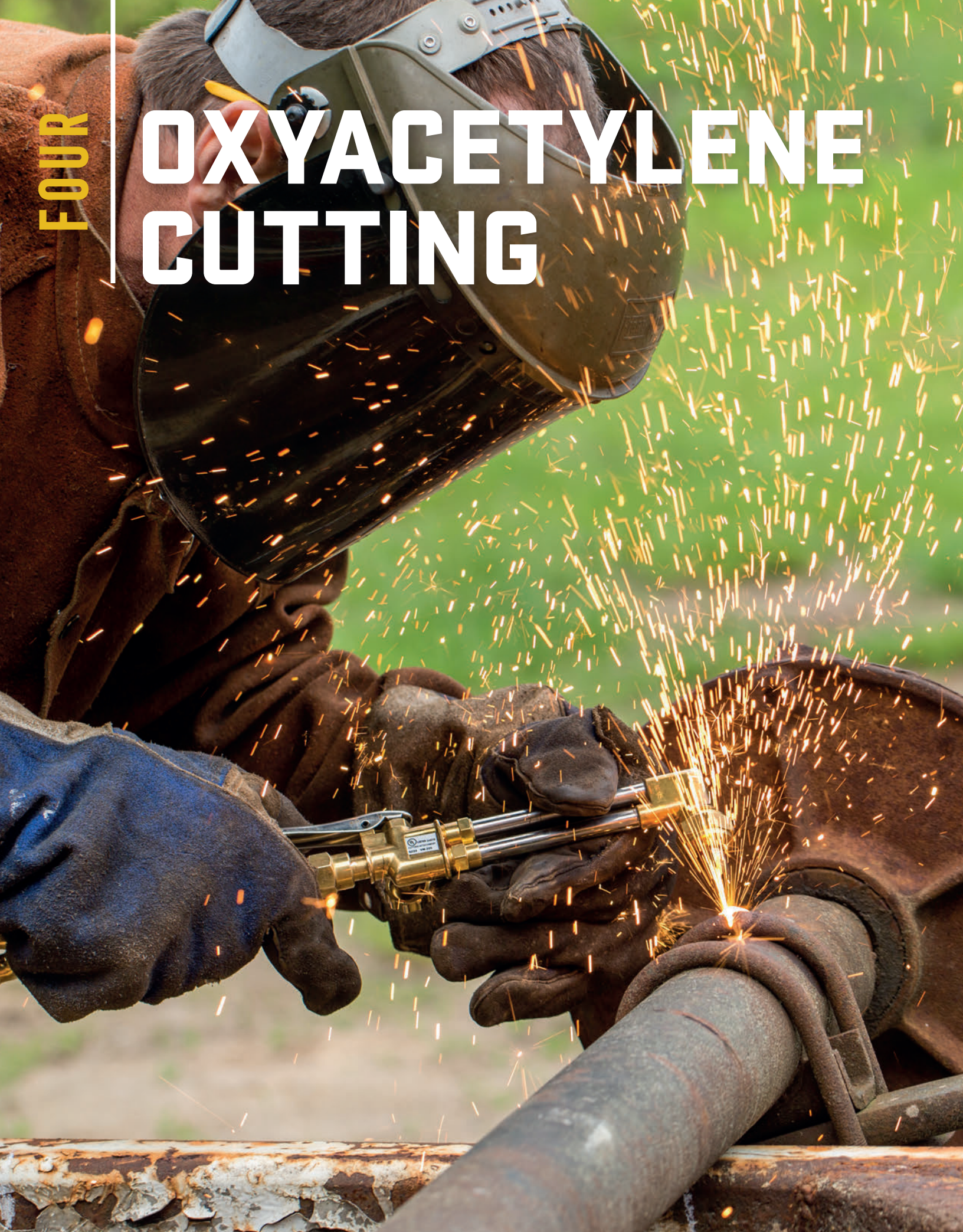
Use a bar or pliers to slowly bend the link back into position. Take your time, and don't bend it too far.

2

Good as new, this side link is ready to be returned to service.

FOUR

OXYACETYLENE CUTTING



As with welding, heat produced by combining oxygen and a fuel gas can cut through metal. In fact, much more acetylene is used for cutting metals than for welding them, and, for many cutting applications, there is no more effective and efficient process. Commonly used in construction, manufacturing, and repair operations, cutting equipment is inexpensive, portable, and easy to use. While acetylene is the standard fuel gas used for cutting, there are alternative fuels that offer specific performance characteristics. This chapter explains how the oxygen-fuel cutting process works, as well as its capabilities and limitations.

How Oxyacetylene Cutting Works

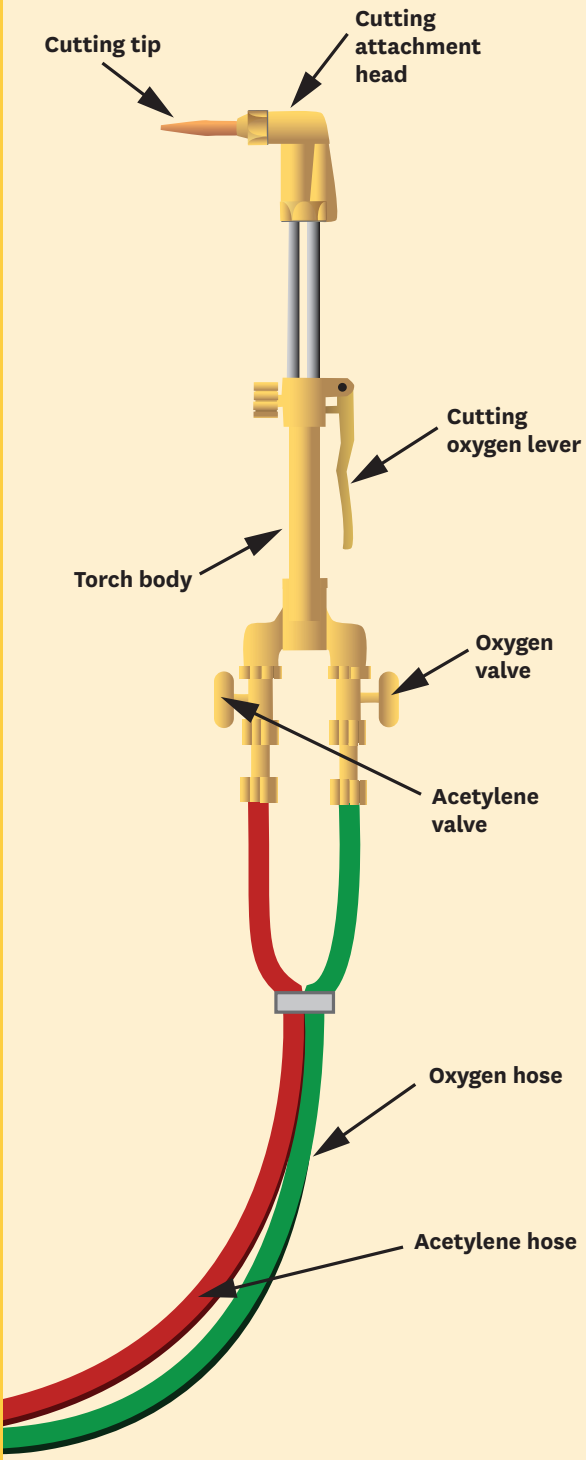
The process for oxyacetylene cutting (OAC) is similar to that of oxyacetylene welding (OAW). It can be done with the same setup by easily changing the welding tip for a cutting head. The oxyacetylene flame brings the steel at the beginning of the cut up to the kindling temperature of 1,600°F (871°C). At the kindling temperature, steel will readily burn in the presence of oxygen. When the oxygen lever is turned on, the pure oxygen stream, along with the steel at kindling temperature, causes a chemical reaction called *oxidation,* which produces slag. This slag has a melting point much lower than the melting point of steel itself and readily runs out of the cut, or *kerf.* The force of the oxygen stream provides additional help to clear the kerf of molten oxides.

In addition to the oxyacetylene preheat flame, the burning of the iron in the oxygen stream releases large amounts of heat. This aids the cutting action, particularly when cutting thick steel. Moving the torch across the work produces continuous cutting action, and straight, curved, or beveled cuts can be made easily. Conventional OAW equipment (outfit) is readily converted to perform light to heavy OAC by exchanging the welding nozzle on the torch handle with a cutting accessory head that attaches to the handle (see page 64).

OAC has no practical high limit of material thickness. Steel that's 7 feet thick is routinely cut in heavy industry, and 14-foot cuts are not uncommon. However, the low limit is 20 gauge (0.035 inch) steel, which can be cut with a large tip-to-plate angle (tipping the cutting head inline to the cut) and a fast travel speed. With still thinner material, the cut becomes irregular with uncontrollable melting. Therefore, very thin sheets are best cut with laser or plasma cutters.

Oxyacetylene Cutting

The setup for oxyacetylene cutting is the same as it is for welding (see page 12), except a cutting torch is used instead of a welding torch.



PROS AND CONS OF OAC

ADVANTAGES

- Low cost compared with machine tool cutting equipment
- No external power required
- Readily portable
- Typically cuts steel faster than by conventional machining process
- Good choice for cutting mild steel, low-alloy steel, cast iron, and titanium
- Easy to change cutting direction
- Economical method for plate edge preparation for groove and bevel weld joints
- Large plates can be cut in place
- Parts with unusual shapes and thickness variations hard to produce with conventional machinery are easily produced with OAC
- Can be automated using tracks, patterns, or computers to guide the torch
- Holes or centers can be cut out without starting from an edge

DISADVANTAGES

- Dimensional tolerance of OAC is dramatically poorer than machine tool-based cutting
- Limited to steel and cast steel (ferrous) materials; not a good choice for aluminum, brass, copper, lead, magnesium, stainless steel, or zinc
- Both the preheat flame and the stream of molten slag present fire and burn hazards
- Requires proper fume control
- Some steels may need preheat, post-heat, or both to control the metallurgy and properties of the steel adjacent to the cut
- High-alloy steels and cast iron need additional process modifications

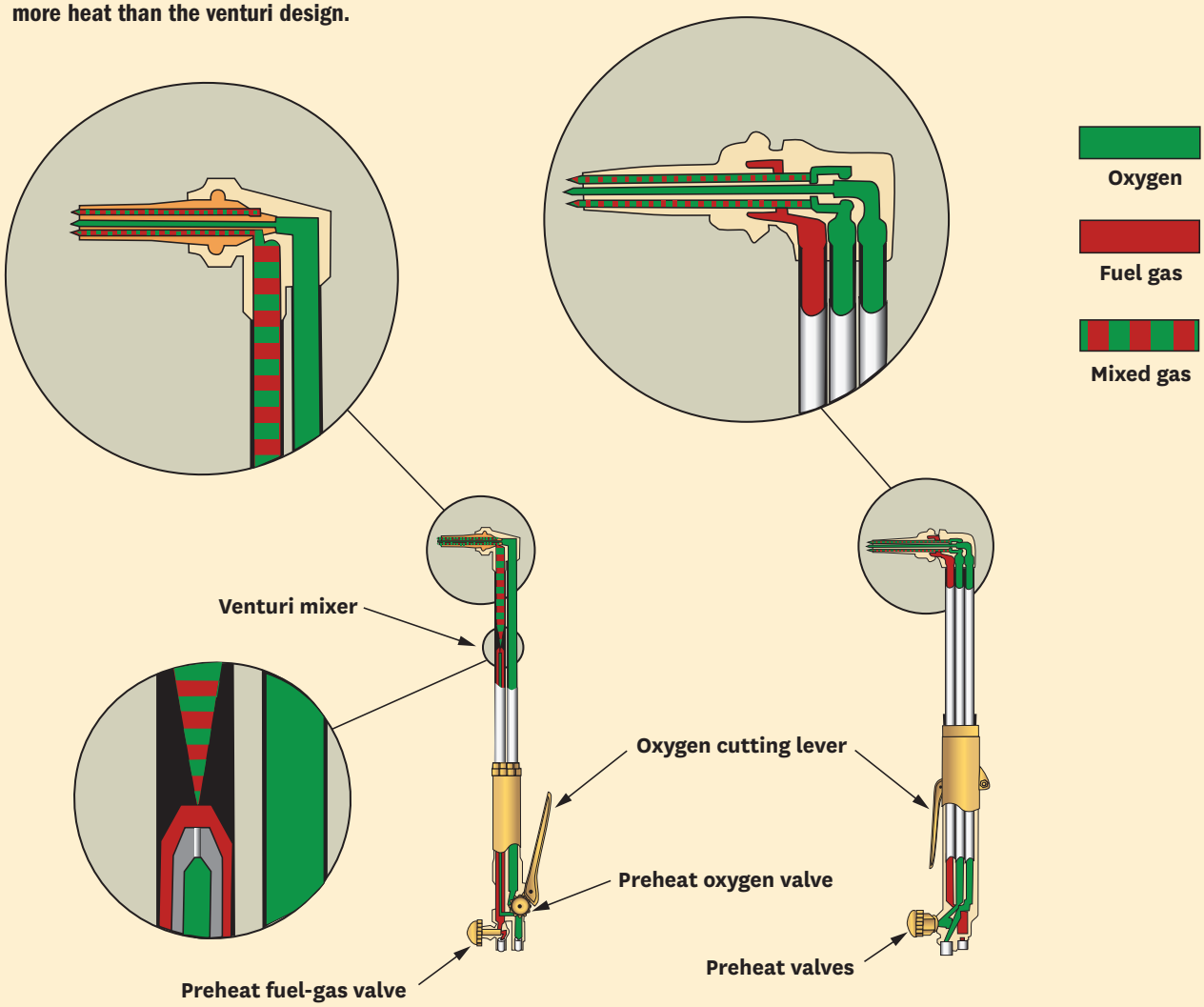
Using a Cutting Head on the Welding Torch

The OAC cutting head is capable of mixing oxygen and acetylene to produce an approximate temperature of 6,300°F (3,100°C), and it can deliver a stream of pure oxygen to the cutting point. An oxygen lever opens this pure oxygen stream when the welder depresses it.

The torch on the left side of the illustration below uses an injection chamber or venturi to draw the fuel gas into the oxygen stream. The torch depicted on the right uses a mixing chamber to bring the gases together and is also known as balanced-pressure, positive-pressure, or medium-pressure torch. The advantage of the mixing chamber design torch is that it operates at higher fuel-gas pressures and can supply more heat than the venturi design. The venturi design, when adjusted properly, creates a near-perfect cutting flame that uses the fuel gas more efficiently.

Oxy-fuel Cutting Torches

An injector cutting torch (left) is used when a lower, more economical fuel-gas pressure can be used. The more commonly used positive pressure cutting torch (right) is used when a higher fuel-gas pressure is needed, supplying more heat than the venturi design.



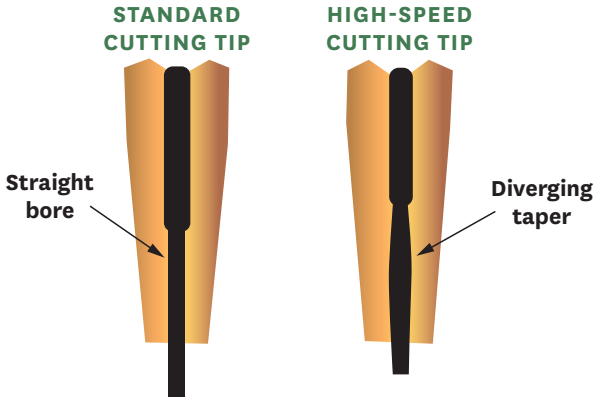
CUTTING TIPS

OAC tips are made of copper and can easily be damaged if dropped. Tips from one torch maker cannot, in general, be used in another manufacturer's torch. Select the correct tip size for the thickness of the metal to be cut.

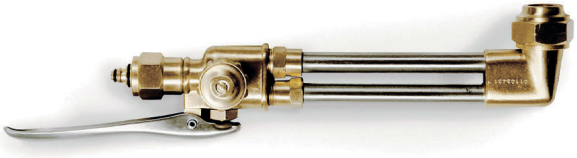
If you have removed the tip nut that retains the torch tip, and the torch tip is stuck in the torch body, a gentle tap on the back of the torch head with a plastic hammer will release the tip.

Always take care when cleaning the tip to avoid breaking off the tip cleaner inside the torch tip or reaming out the holes.

Regular cutting tips have a straight-bore oxygen channel and operate from 30 to 60 psi (2 to 4 bar). High-speed tips have a diverging taper and permit operation at oxygen pressures from 60 to 100 psi (4 to 7 bar). This permits a 20 percent increase in cutting speed. They are used in setups that are exclusively for cutting.



The diverging taper of a high-speed cutting tip allows for a higher oxygen pressure and a 20 percent increase in cutting speed.



This is an example of a typical cutting torch. Note the lever for controlling the flow of oxygen.

The copper tip attaches to the end of the cutting torch.

OTHER FUELS THAT CAN BE USED IN OXY-FUEL CUTTING

When a fuel other than acetylene is used, the process is called oxy-fuel cutting (OFC). These alternative fuels include:

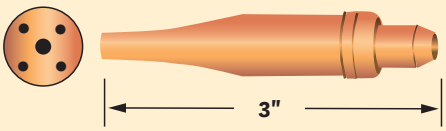
- **Propane**
- **Natural gas**
- **Methyl acetylene-propadiene stabilized (known as MPS or MAPP)**

Although acetylene produces higher preheat temperature, alternative fuels are far more stable than acetylene, and therefore much safer to handle. An alternative fuel may also offer significant cost savings. Fuel selection is a complex matter involving material thickness; cutting speeds; preheat time; fuel performance on straight lines, curves, and bevels; and the impact of these factors on the total cost.

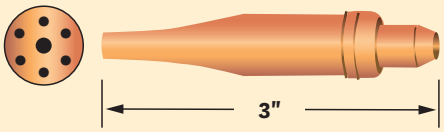
While alternative fuels do not produce the high flame temperature of acetylene, some can produce a greater volume of heat output throughout the outer flame envelope. This gives an advantage to some alternative fuels in cutting thick steels. In OFC, torch tip designs are frequently different because alternative fuels may be supplied at lower pressures, have different ratios of fuel to oxygen, and have different flame and burn rate characteristics. Several manufacturers offer alternative fuel torches.

Oxyacetylene Cutting Tips

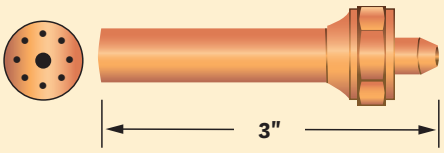
Some oxyacetylene cutting tips are more specialized and only used for particular tasks.



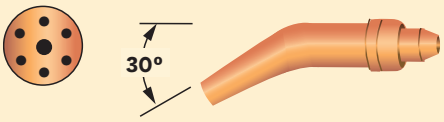
Light preheat for hand cutting clean plate.



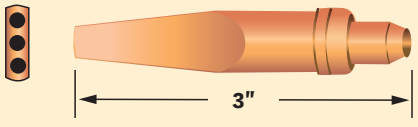
Medium preheat for general-purpose hand cutting.



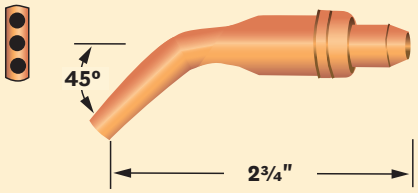
Heavy preheat for thick metal cutting.



Medium preheat for general-purpose hand cutting with 30-degree bevels with torch perpendicular to work.



Medium preheat for clean plate, straight line, or circle machine cutting.



Medium preheat for general-purpose hand cutting.

Setting Up Cutting Torch Equipment

Setting up the cutting torch uses the same steps as setting up for oxyacetylene welding. Once those steps are complete, inspect and clean the cutting torch tip, fasten the torch to the handle, and proceed to light the cutting torch and adjust the cutting torch, as detailed below. See page 76 for proper procedure for shutting down the equipment when you're finished.

LIGHTING AND ADJUSTING THE CUTTING TORCH

- Follow the steps of securing the cylinders; installing the regulators, hoses, and torch; purging the hoses of air; and setting the regulator pressures (from cutting reference tables) for ½-inch steel: acetylene at 6 psi (0.4 bar) and oxygen at 30 psi (2 bar).

WARNING: Never adjust the acetylene regulator pressure above 15 psi (1 bar) as an explosive disassociation of the acetylene could occur.

- Press the oxygen lever/valve on the back end of the torch all the way.
- Recheck the low-pressure gauge pressures to make sure the working pressures are not rising. If the working pressures rise, it means that the regulator is leaking. If so, immediately shut down the cylinders at the cylinder valves, as continued leaking could lead to regulator diaphragm rupture and a serious accident.
- Make sure you have on your number 5 shade welding goggles or facemask.
- Light the torch by opening the acetylene valve on the torch handle about 1/16 turn and light the acetylene using a flint igniter, holding the igniter at an angle to the tip. A large, smoky, orange flame will result.
- Increase the flame size by slowly opening the acetylene valve until most of the smoke disappears.
- Open the oxygen preheat valve on the middle of the torch and adjust for a neutral flame.
- Actuate the cutting oxygen lever and examine the preheat cone flames. If they are not neutral, adjust the preheat oxygen valve to keep the preheat flames neutral while cutting, as the hose pressure may drop when the cutting oxygen lever is pressed.
- Make sure your gas hoses are off the floor or ground to prevent sparks and slag from melting them.
- You are ready to begin cutting.

SELECTING AND ADJUSTING PRESSURE RANGES

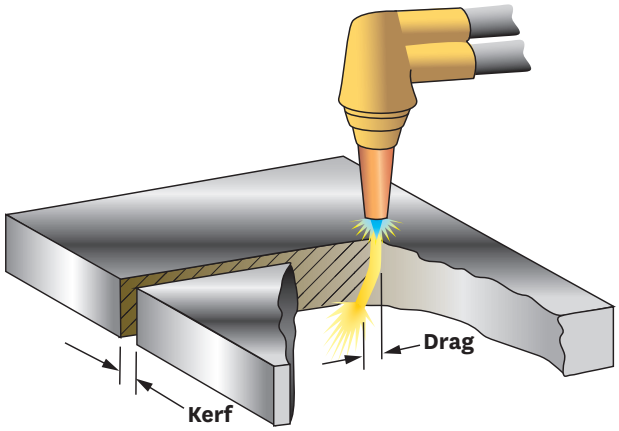
Referring to your specific material and thickness, use a torch manufacturer's table to determine the correct tip size, starting oxygen pressure, and acetylene pressure. Keep in mind that these are suggested starting pressure ranges. Fine-tuning of the pressures may be needed to get the best combination of speed and quality.

Basic Cutting Techniques

Cutting involves removing material, and the width of the cut — the material removed — is known as the kerf. When flame cutting, this is due to oxidation of the metal along the line of the cut. The kerf is equal to the bore size of the cutting tip. In steel under 2 inches in thickness, it is possible to hold the kerf to about 1/64 inch. Cutting thicker steel requires more oxygen, which requires a larger oxygen orifice size, greater oxygen flow rates, and a larger oxygen stream. These result in a wider kerf.

DEALING WITH DRAG

The distance between the cutting action at the top and bottom of the kerf is called *drag*. When the oxygen stream enters the top of the kerf and exits the bottom of the kerf directly below, the drag is said to be zero. If the cutting speed is increased (or the oxygen flow decreased), oxygen in the lower portion of the kerf decreases and the kinetic energy of the oxygen stream drops, slowing cutting action in the bottom of the cut. This causes the cutting action at the bottom of the kerf to lag behind the cutting action at the top. Drag may also be expressed as a percentage of the thickness of the cut. Excessive drag can cause loss of cutting action in thick cuts, which can be difficult to restart. Conversely, excessive oxygen flow, cutting too slowly, or damaged orifices may cause reverse drag, leading to rough cut edges and excessive slag adhesion.



The width of the cut is the kerf; drag is the distance between the cutting action at the top and bottom of the kerf.

Choosing a Tip to Achieve the Right Bore Size

The numbering system for cutting tip sizing, like welding tip sizing, is not standardized in the welding industry. The drill sizing is standard, but the manufacturer's numbers placed on the tips are not standard. The cutting drill bore size indicates the cutting orifice size and the thickness of the material that the tip can cut.

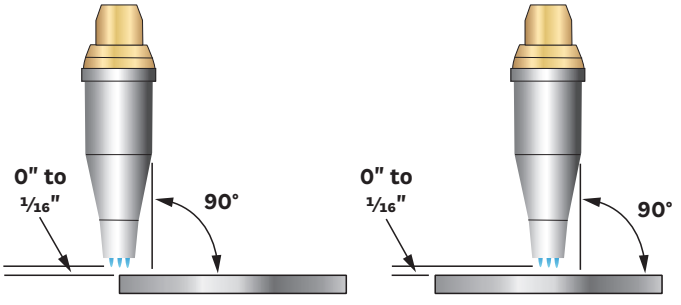
Plate Thickness	Bore Drill Size	Orifice Size
¼–½"	68–53 DR	0.031–0.059"
¾"	62–53 DR	0.038–0.059"
1"	56–53 DR	0.046–0.059"
1½–2"	51–46 DR	0.067–0.081"
3–5"	46–44 DR	0.081–0.086"
6–8"	40–39 DR	0.098–0.100"
10"	39–35 DR	0.100–0.110"

CUTTING ¼-TO ½-INCH-THICK METAL

1 Hold the cutting torch tip perpendicular to the metal with the preheat flames just touching the metal to be cut.

2 Start the cut at the edge of the stock by preheating the edge of the stock. In thicker material, the torch may be angled away from the direction of travel so the preheat flame strikes down the edge of the material. When the stock becomes a dull cherry-red, begin cutting by squeezing the oxygen cutting lever. Hold the torch tip perpendicular to the surface of the stock when cutting action has begun.

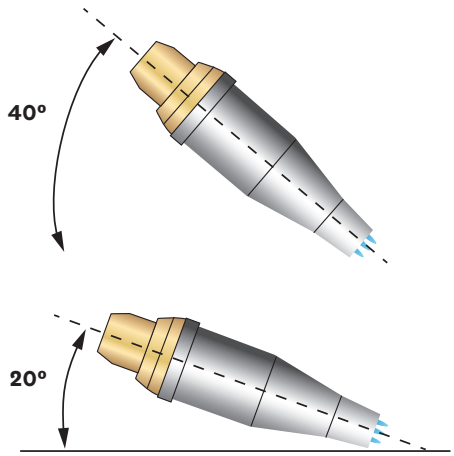
3 Move the torch along the cut line in a steady motion, keeping the cutting tip preheat flames just touching the metal. For right-handed welders, cutting from right to left allows the welder to see the marks of the cutting line more easily. Left-handers usually prefer cutting left to right.



Position of cutting torch tip on ¼-inch and thicker plate, starting (left) and cutting (right)

CUTTING ⅛-INCH-THICK OR THINNER METAL

1. Set the oxygen pressure at 15 psi (1 bar).
2. Utilize the smallest cutting tip available with two preheat flames.
3. Hold the torch at a 40-degree angle to start the cut, and adjust to as much as a 20-degree angle to increase kerf width, if needed.
4. Adjust the flame to the smallest preheat flame that will permit cutting.



The torch position for cutting thin sheet metal can be between 20 and 40 degrees.

PREVENTING SLAG ACCUMULATION

When cutting thin-gauge sheet metal, if slag accumulates on the underside of the workpiece, angle the torch away from the side you will use. This allows the slag to form on the scrap side of the kerf, keeping it off the good section. Too much slag may indicate that the equipment is not set up properly.

CUTTING STEEL THAT'S THICKER THAN 1 INCH

Cutting thick steel requires more oxygen than cutting thin steel and may require a special oxygen regulator that can deliver more oxygen volume at higher-than-welding pressures. Larger-diameter hoses may also be required. The welding acetylene regulator is fine for cutting. Also, since there is much higher oxygen consumption and more rapid cylinder depletion than in welding operations, the typical cutting regulator is a two-stage regulator to maintain a constant working pressure as the cylinder gas dwindles. Oxygen regulators designed specifically for cutting usually have low-pressure gauges (on the output or torch side of the regulators) with higher pressure calibrations than welding regulators. OFC operations on extremely thick metals can require 100 to 150 psi (6.8 to 10 bar) oxygen pressures. Volume demands may require several acetylene cylinders to be paired together.

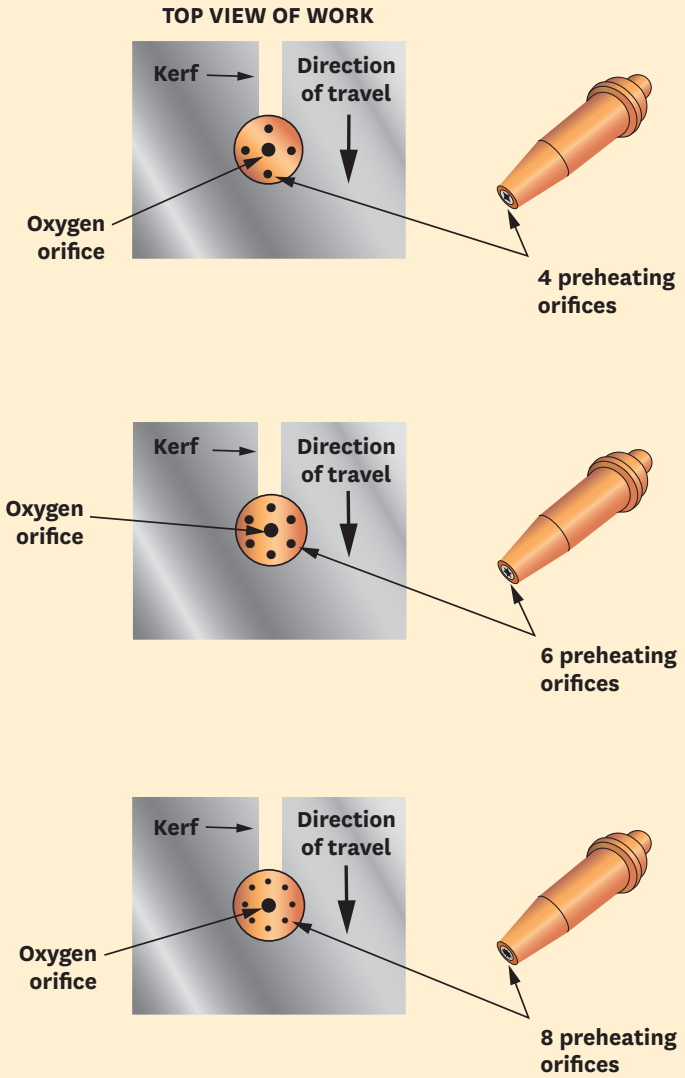
Optimum Pressure and Gas Flow Settings for Cutting Various Metal Thicknesses

Plate Thickness	Oxygen PSIG	Fuel Gas PSIG	Oxygen Bore Drill Size
⅛"	20–25	3–5	0.031"
⅛–¼"	20–25	3–5	0.036"
¼–½"	25–35	3–5	0.040"
½–¾"	30–35	3–5	0.046"
¾–1½"	35–45	3–7	0.059"
1½–2½"	40–50	4–10	0.067"
2½–3"	45–55	5–10	0.093"
3½–5"	45–55	5–10	0.110"
5–8"	45–60	7–10	0.120"

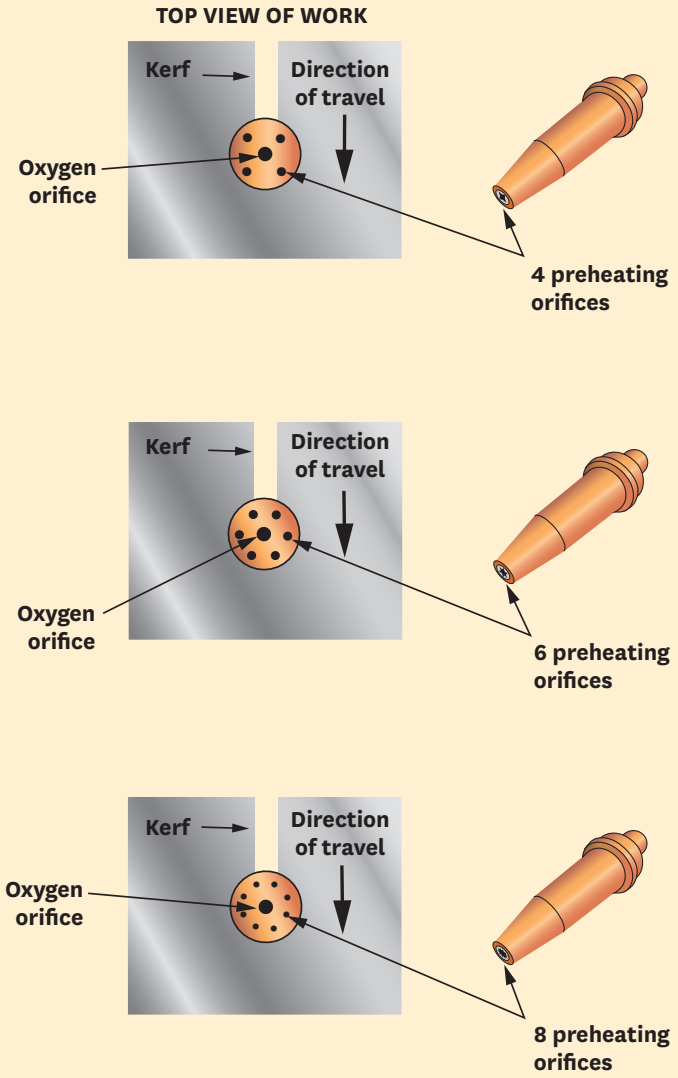
ADJUSTING TORCH TIPS

If there are two preheat orifices in the torch tip, rotate the tip so that a line drawn between the orifices would be perpendicular to the cut line for a normal cut. If there are more than two orifices, rotate the tip so that two of the orifices are aligned with the cut line and the remaining orifices are divided equally on both sides of the cut line. This symmetrical preheating improves the quality of the cut. The illustrations below show the positioning for normal cut and for a bevel cut.

LOCATION OF PREHEAT ORIFICES IN RELATION TO KERF FOR A NORMAL CUT

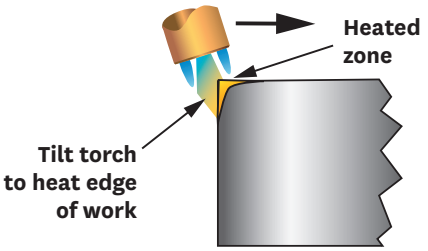


LOCATION OF PREHEAT ORIFICES IN RELATION TO KERF FOR A BEVEL CUT

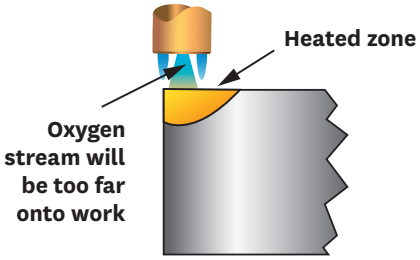


STARTING A CUT ON HEAVY STEEL

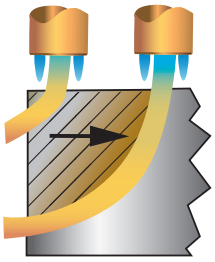
Properly preheating and cutting into the edge of a thick piece of steel, before continuing to move the torch, makes for a smoother, cleaner cut.



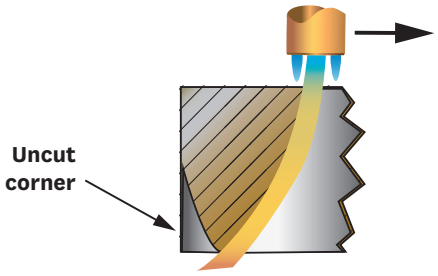
A Preheat primarily on starting face



B Tip too far onto work with heating too much on top



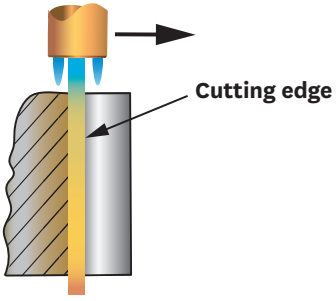
C Action of cut from (B)



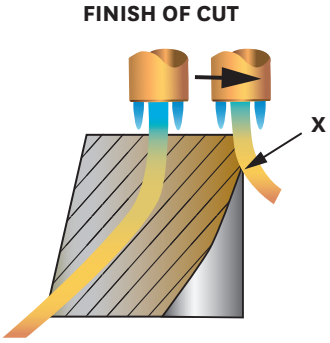
D Typical result from (B)

ENDING A HEAVY CUT

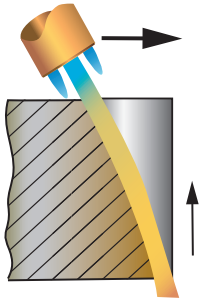
As the end of the cut nears, tilt the torch away from the direction of travel. This permits the bottom of the cutting action to proceed ahead of the top cutting action and eliminates premature breakout of the flame, which leaves a triangle at the end of the cut.



A Typical of balanced conditions



B Drag causes cut-through at X

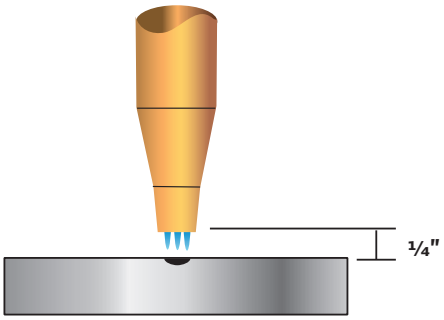


C Tilt torch at end of cut to sever plate from bottom to top

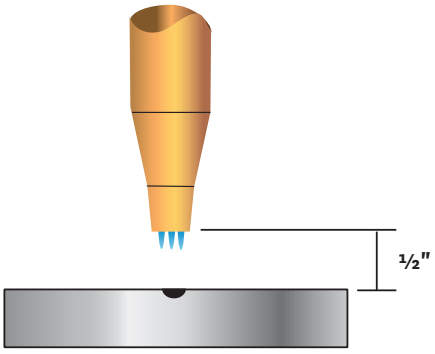
PIERCING STEEL WITH OXYACETYLENE

Begin by preheating the material in the pierce location to a dull red color (kindling temperature), with the torch perpendicular to the metal. Then, slightly raise the torch from the surface and angle the tip away from perpendicular. This prevents the slag that is blown back from the surface from landing on or in the torch tip. Squeeze the oxygen lever to start the cutting action. As soon as the material is completely pierced, restore the tip to perpendicular and the pre-heat flame to just above the surface. Complete the cut.

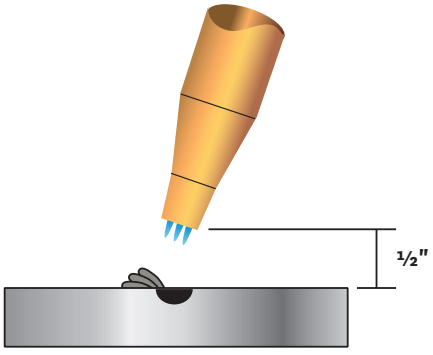
If you're cutting a small hole and want to protect the surrounding material from the cutting action, drill a ¼-inch hole at the starting point. Begin the cutting action through the hole.



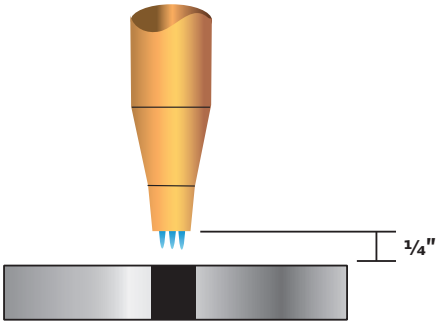
1 Preheat the material with the torch tip ¼ inch away from the surface.



2 Raise the torch tip to ½ inch above the material.



3 Angle the torch away from perpendicular and squeeze the oxygen lever.

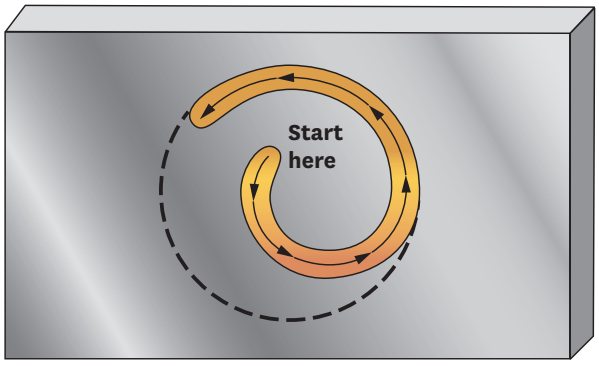


4 Restore the torch angle to perpendicular and the torch tip to ¼ inch away from the material once it is fully pierced.

An oxyacetylene cutting torch is ideal for cutting through thick steel. The metal trash barrel underneath helps contain the sparks and molten slag.

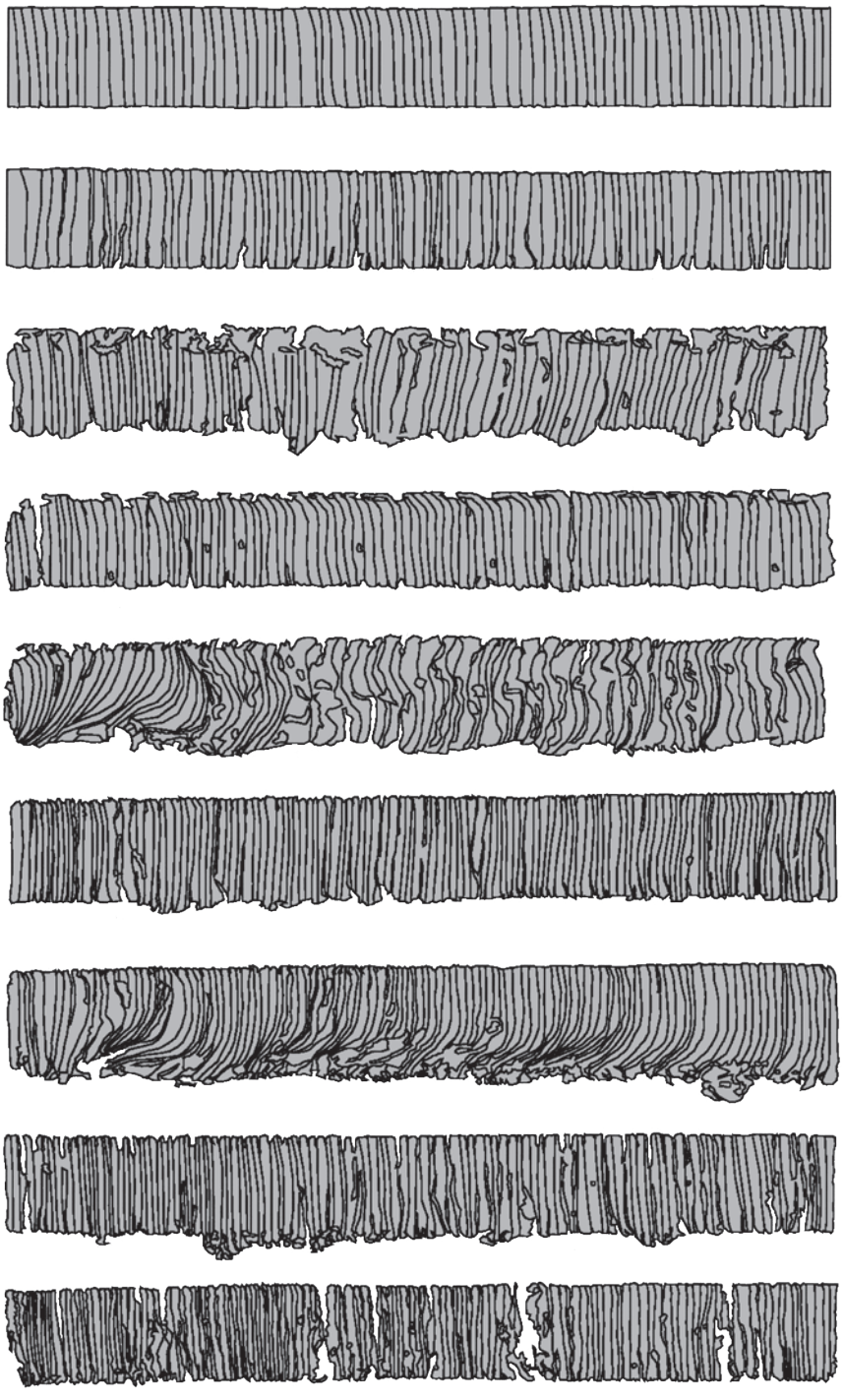
CUTTING OUT A CIRCLE

Pierce the material inside the circle and away from the finished edge. When the cutting action is established, extend the cut into a spiral and begin cutting the circle itself. When cutting small circles, prevent damage to the finished edge by drilling a ¼-inch hole in the center of the circle, and begin the cut through the inside of the hole, then spiral out to the edge. There are also circle-cutting jigs available, or you can find a pipe fitting or similar item of the right size and use it as a guide.



Correcting Defective Edges

Compare the cut edge of your work with the drawings below to diagnose any problems.

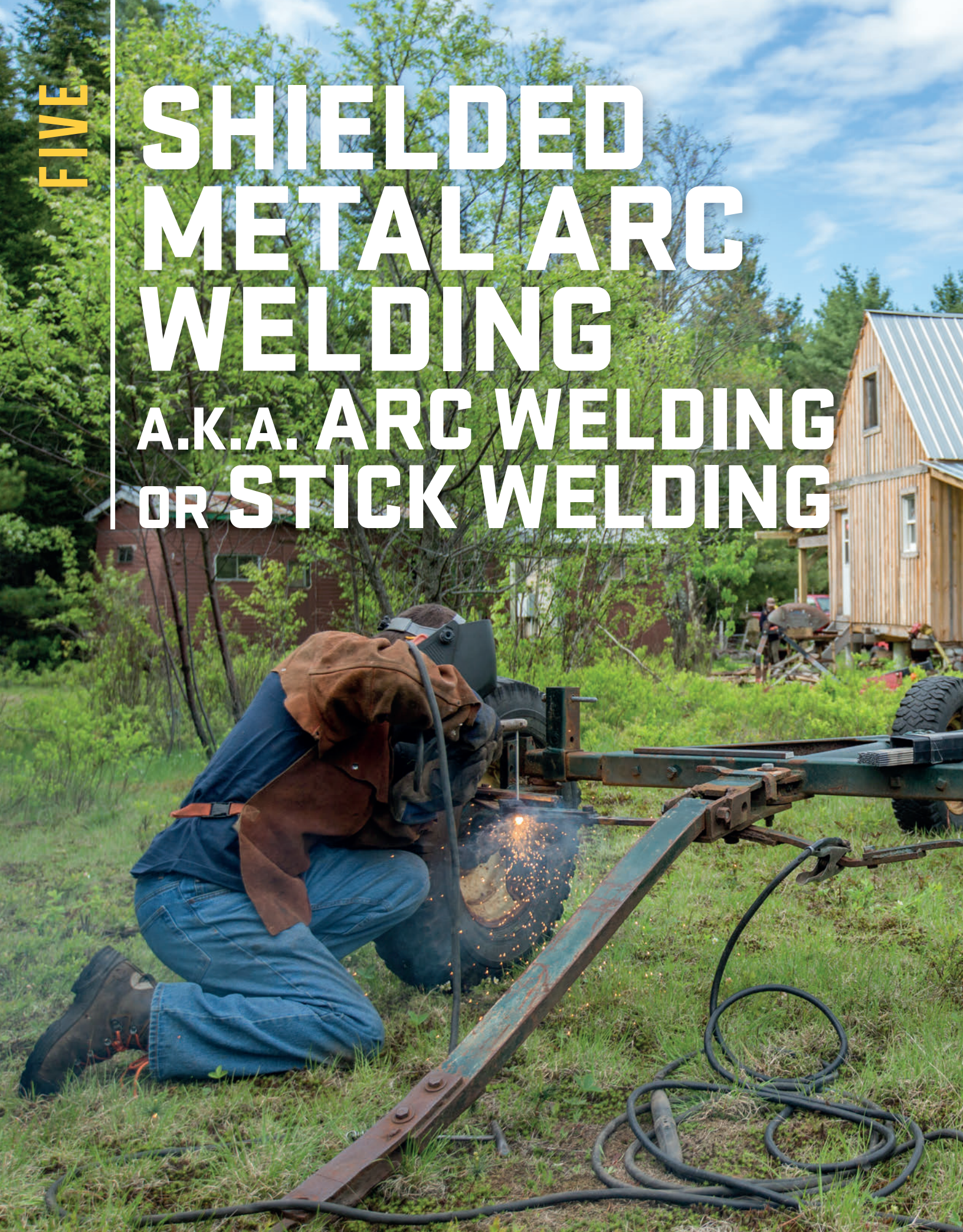


1. A good cut from oxyacetylene on 1-inch steel plate. The plate edge is square and the drag lines are nearly vertical.
2. Preheat flames were too small for this cut and the cutting speed too slow, causing bad gouging at the bottom.
3. Preheating flames were too long with the result that the top melted over and the cut edge is irregular.
4. Oxygen pressure too low with the result that the top edge melted over because of slow cutting speed.
5. Oxygen pressure too high and the nozzle size too small, resulting in loss of control of cutting action.
6. Cutting speed too slow, resulting in dragline imperfections.
7. Cutting speed too fast with pronounced break in dragline and irregularly cut edge.
8. Torch travel was unsteady, resulting in wavy and irregularly cut edge.
9. Cut was lost and carelessly restarted, causing bad gouges at restart point.

FIVE

SHIELDED METAL ARC WELDING

A.K.A. ARC WELDING OR STICK WELDING



Shielded metal arc welding (SMAW), as designated by the American Welding Society, is also referred to as arc welding, and more commonly, stick welding, because of the appearance of the electrodes that are used. The process begins when an electric circuit is established from the power supply, through the electrode, the welding arc, the workpiece, the ground cable clamped to the workpiece, and back to the power supply. Electrons flowing through the gap between the electrode and the work make an electric arc that produces temperatures that exceed 6,000ºF (3,300ºC). As the arc heats the electrode and the work beneath it, tiny globules of metal form at the tip of the electrode and transfer to the molten weld pool on the work. As the electrode moves away from the molten pool, the molten mixture of electrode and base metals solidifies and the weld is complete.

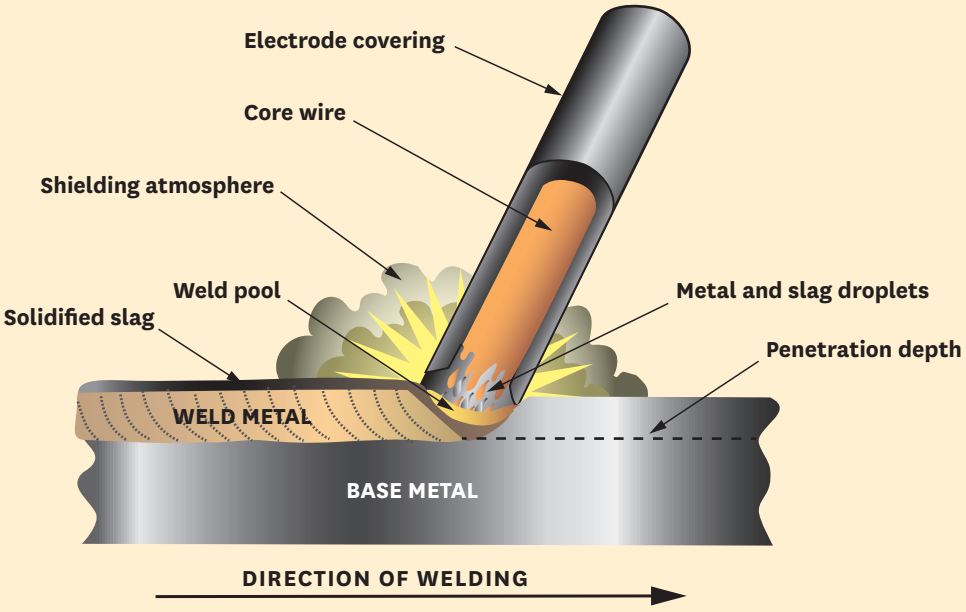
How the Stick Welding Process Works

The electrode is coated with a cleaning flux, which varies for each type of welding rod. Heat from the electric current causes the flux to combust and decompose as the rod is consumed. This creates a gaseous shield to protect the electrode tip, the work, and the molten pool from atmospheric contamination. The flux contains materials that coat the molten steel droplets as they transfer to the weld and become slag after cooling. This slag also floats on the weld puddle's surface and solidifies over the weld bead when cool, where it protects the molten metal and slows the cooling rate.

The flux coating on some electrodes contains metal powder to provide additional heat and filler to increase the deposition rate. The electrode flux and metal filler electrode determine the chemical, electrical, mechanical, and metallurgical properties of the weld as well as the electrode handling characteristics. Only 50 percent of the heat power furnished by the power supply is applied toward heating the weld; the rest is lost to radiation, the surrounding base metal, and the weld plume (the gas emissions around the weld).

Stick Welding

Here is a close-up look at the tip of a stick welding electrode as it penetrates the base metal and is deposited into the weld pool.



One of the benefits of a portable gas-powered welder is that it allows you the flexibility to do in-field repairs. This gate was repaired in place, instead of having to remove and transport it back to the shop.

When to Use Stick Welding

Stick welding can be used for welds ⅛ inch thick and thicker. Thicknesses less than ⅛ inch can be joined with stick welding, but this requires much greater skill, while those over ¾ inch are more economically done by other welding methods. Therefore, stick welding is most commonly used for materials between ⅛ and ¾ inch thick. Use stick welding for the metals listed below. Although aluminum welding *can* be done by SMAW, it seldom is; other, better processes exist. Note that some of these metals require preheat, post-heat, or both to prevent cracking.

METALS THAT CAN BE STICK WELDED

- Aluminum
- Bronze
- Carbon steel
- Cast iron
- Hard-facing
- High-strength steels
- Low-alloy steels
- Malleable iron
- Nickel
- Stainless steels

PROS AND CONS OF THE STICK WELDING PROCESS

ADVANTAGES

- Low-cost equipment
- Can weld many different metals, including the most commonly used metals and alloys
- Relatively portable and useful in confined spaces
- Same equipment is used for welds in thicknesses from 1/16 inch to several feet in thickness, with different current settings
- Welds can be performed in any position
- The process is less affected by wind and drafts than gas-shielded processes
- There is no upper limit on thickness of metal to be welded
- It can be performed under most weather conditions
- Better choice for repair work when base metal has been exposed to oils, greases, oxidation, and complete cleaning of the work area is limited

DISADVANTAGES

- Not suitable for metal sheets under 1/16 inch thick
- Operator duty cycle and overall deposition rate are usually lower with SMAW than with wire-fed processes because the SMAW process must be stopped when the electrode is consumed and needs to be changed
- Not all of the electrode can be used; the remaining stub in the electrode handle must be discarded, wasting 1 to 2 inches of electrode
- Frequent stops and starts during electrode changes can introduce weld defects

SMAW is not permitted when the weld is exposed to rain, snow, and blowing sand, or when the base metal is below 0°F (–18°C). Temporary shelters, known as "dog houses", around the weld site permit welding during these conditions, increase the comfort of the welder, and help raise the weld temperature. Preheating the weld base metal to 70°F (21°C) with multi-flame (or rosebud) tips allows welding to proceed when the outside temperature is below 0°F (–18°C).

Basic Equipment Setup for Stick Welding

A basic stick welding setup has a few, simple components, and is generally sold as a complete unit. The basic setup consists of:

- Constant-current (CC) welding power supply
- Electrode holder, lead, and its terminals
- Ground clamp, lead, and its terminals
- Welding electrodes

WELDING POWER SUPPLIES

Constant-current (CC) welding power supplies are best for SMAW because this type of power supply helps to provide a constant current to the arc despite changing arc length during welding. This characteristic gives the welder control over weld pool size and still limits maximum arc current. Some variation in arc length is inevitable as the welder moves the electrode along the weld, but the CC welding supply ensures a stable arc as these variations occur.

TYPES OF CURRENT. The following types of current are used in stick welding. Most midrange and high-end machines allow for AC, DCEN, and DCEP settings.

- Alternating current (AC)
- Direct current electrode negative (DCEN = DCSP)
- Direct current electrode positive (DCEP = DCRP)

Direct current (DC) always provides the most stable arc and more even metal transfer than alternating current (AC). Once struck, the DC arc remains continuous and smooth. When welding with AC, the arc extinguishes and restrikes 120 times per second, as the current and voltage reverse direction. The DC arc has good wetting action of the molten weld metal and uniform weld bead size at low welding currents. For this reason, a DC arc is excellent for welding thin sections. DC is preferred to AC on overhead and vertical welding jobs because it has a shorter arc. Sometimes arc blow (see page 102) is a serious problem and

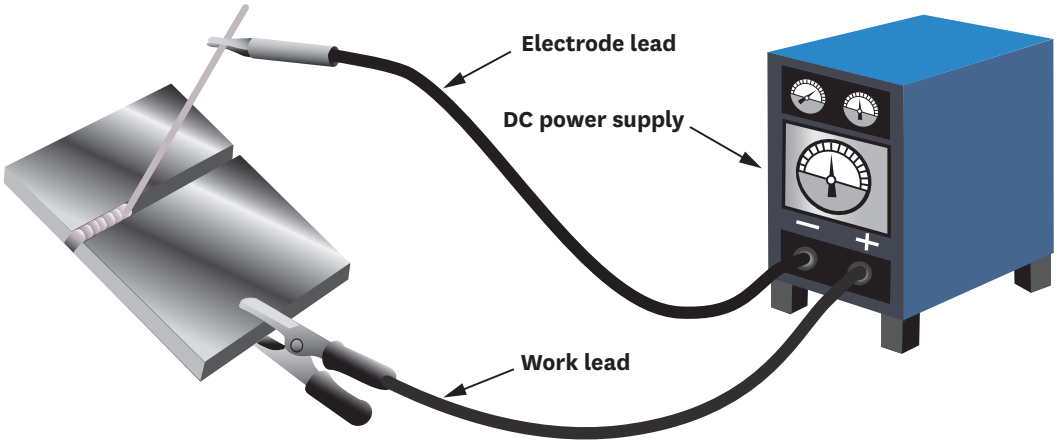
Here are two common setups that include the power supply, electrode holder, and ground clamps.

the only solution may be to switch to AC. Most combination electrodes designed for AC or DC operation work better on DC.

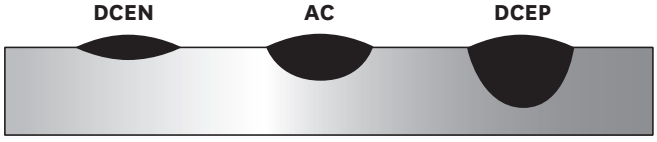
DCEN stands for direct current electrode negative. This is also called *DCSP*, or direct current straight polarity. DCEN produces less penetration than DCEP (described below) but has a higher electrode burn-off rate. This is a good choice for welding thinner metals.

DCEP stands for direct current electrode positive. This is also called *DCRP*, or direct current reverse polarity. DCEP is especially useful welding aluminum, beryllium-copper, and magnesium because of its surface-cleaning action, which permits welding these metals without flux. DCEP produces better penetration than DCEN but has a lower electrode burn-off rate. This is a good choice for welding thicker metals.

The power supply should be blown out with compressed air to remove slag, grinding dust, and other dust from its interior. If you use your equipment frequently, perform the maintenance on a monthly basis.



This welder is set up for direct current electrode negative (DCEN). For direct current electrode positive (DCEP), switch the polarity of the electrode lead and the work lead (ground cable).



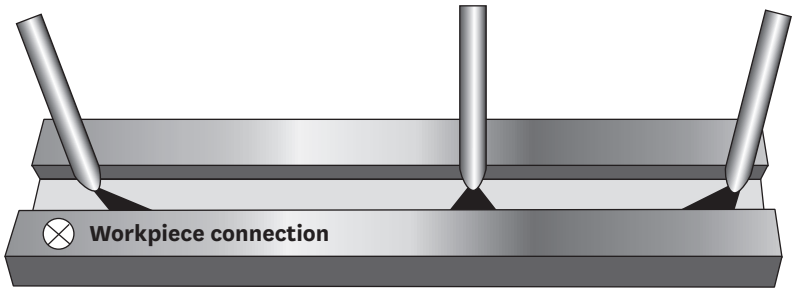
The effect of weld bead penetration at same welding current is clearly visible; this illustrates weld bead penetration from lowest to highest heat going into the weld.

CORRECTING ARC BLOW

Whenever current flows, it creates a magnetic field around the conductor. Any shape of wire other than a straight line will produce an asymmetrical field along the wire — points where the field is either stronger or weaker than average. At currents above 600 amperes, the force created by the unevenness of the field may even cause the wire itself to move. More often, welders see the arc drawn in a particular direction, like smoke in the wind. This is caused by residual magnetism in the work material, or by the uneven magnetic field caused by current flowing through the material to the work connection. Some welders call this "arc blow."

Ways to reduce arc blow include:

- **Using AC, instead of DC, welding current**
- **Moving the welding work lead to a position where you are welding away from the work lead connection**
- **Using a shorter arc length**
- **Clamping a steel block over the far end (unfinished end) of the weld**
- **Welding away from the base metal edge, or toward a heavier tack or weld**
- **Changing welding direction**



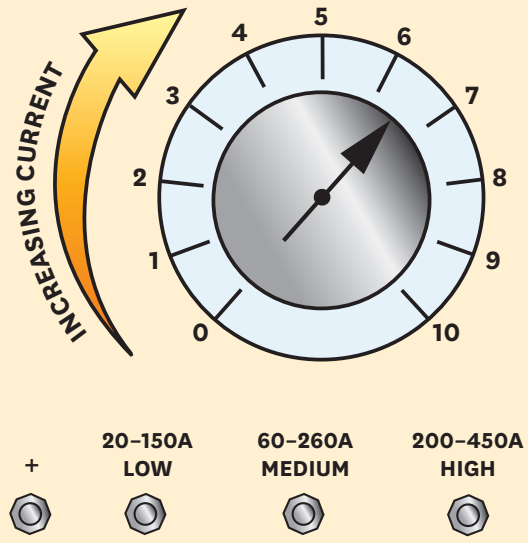
Undesirable arc blow on left and right arc

DETERMINING CURRENT SETTINGS OF WELDING MACHINES

Below are the basic steps for setting the amperage on a SMAW welder. The table on page 103 offers specific recommendations for amperage based on metal thickness, polarity, and electrode choice.

In the illustration on the right, note that the medium tap or coarse setting is in use with an output from 60 to 260 amperes. This means that this tap will provide a minimum current of 60 amperes when the rotary dial is set to 0. The current can be increased to a maximum of 260 amperes, using the dial. Each of the 10 dial settings adds 20 amperes to the setting, with a maximum of 200 amperes. The dial is set to 6.5, or 6.5 × 20 amperes plus the base of 60 amperes, equals 190 amperes.

AMPERAGE SETTING OF A GENERIC WELDING MACHINE



Note that these settings are likely to be approximate, and output current will vary with power line voltage variations, cable length, cable size, and other factors. The best output current setting may be slightly above or below the dial setting.

ELECTRODES AND AMPERAGE RANGE. Once an electrode class and diameter is selected for a task, use the table below to determine the manufacturer's recommended amperage range. Note that there will be some differences between recommended ranges for the same electrode class and diameter so it is important to consult the manufacturer's specification sheet for the electrode you are using. Also, the material thickness will affect the current setting.

Usually it is best to use the lower current range setting. This is because the top of a current range is likely to have less current ripple (AC riding on the top of the DC) than the same current output setting from a higher current range, and will provide a smoother arc.

Note the AC and DC power settings on this stick welding machine.

Recommended Current Ranges for Various Diameter Electrodes

Lincoln Electric Product Name	AWS Class	Electrode Polarity	Sizes and Current Ranges (Amperes)					
			3/32"	1/8"	5/32"	3/16"	7/32"	1/4"
Fleetweld 5P	E6010	DCEP	40–70	75–130	90–175	140–225	200–275	220–325
Fleetweld 35	E6011	AC DC±	50–85 40–75	75–120 70–110	90–160 80–145	120–200 110–180	150–260 135–235	190–300 170–270
Fleetweld 7	E6012	DC – AC	N/A N/A	80–135 90–150	110–180 120–200	155–250 170–270	225–295 250–325	245–325 275–360
Fleetweld 37	E6013	AC DC±	75–105 70–95	110–150 100–135	160–200 145–180	205–260 190–235	N/A N/A	N/A N/A
Fleetweld 47	E7014	AC DCEN	80–100 75–95	110–160 100–145	150–225 135–200	200–280 185–235	260–340 235–305	280–425 260–380
Jetweld LH-70	E7018	DC+ AC	70–100 80–120	90–150 110–170	120–190 135–225	170–280 200–300	210–330 260–380	290–430 325–530
Jetweld 3	E7024	AC DC±	N/A N/A	115–175 100–160	180–240 160–215	240–315 215–285	300–380 270–340	350–450 315–405
Jetweld 2	E6027	AC DC±	N/A N/A	N/A N/A	190–240 175–215	250–300 230–270	300–380 270–340	350–450 315–405
Jetweld LH-3800	E7028	AC DC+	N/A N/A	N/A N/A	180–270 170–240	240–330 210–300	275–410 260–380	360–520 N/A

ELECTRODE HOLDERS AND WORK-LEAD CONNECTIONS

Besides holding the electrode in place, the electrode holder insulates the welder from the welding power supply voltage, thermally insulates the welder from the conducted heat of the electrode, and makes a secure electrical connection between the welding cable and the electrode with a minimum of voltage drop. Poor gripping of the electrode by the electrode holder's jaws will cause poor conduction of electricity, and power intended for the weld will be lost in the holder. The holder will overheat and become to hot to handle. Eventually the heat will deteriorate its electrical insulation properties, exposing the welder to possible electric shock. Most electrode holders have notches where the electrode conductor end fits and will not move. When selecting an electrode holder, it is best to pick the smallest size that can be used without overheating, as it will be the lightest weight and least tiring to work with.

JUDGING ARC LENGTH BY SOUND

Although the correct arc length is usually ⅛ inch, one should never exceed the diameter of the electrode. The sound of the arc is an excellent indicator of arc length. The proper arc length sounds like the crackling of bacon and eggs frying. Too short an arc, makes a sputtering sound; too long an arc, a humming sound.

Position the bare metal end of the electrode in the holder. Many stick welding electrode holders can clamp the electrode in a variety of positions.

Electrodes come in a variety of lengths, thicknesses, and types of flux coating.

Selecting Electrodes for Stick Welding

Stick welding electrodes contain a solid or cast-metal core wire covered by a thick flux coating. Every change of flux composition and thickness alters the operating characteristics. These changes, along with the current type and polarity, determine how the rod will handle and what type of bead it will deposit. Electrodes are made in lengths from 9 to 18 inches. Some electrodes are made with a metallic tube containing a mixture of metal powders.

FUNCTIONS OF THE ROD FLUX COATING

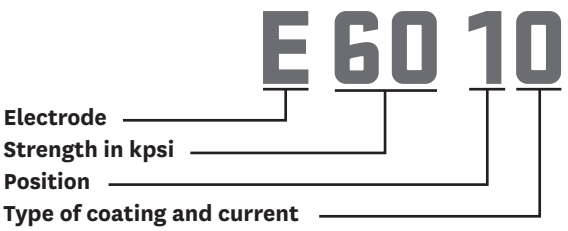
The principal function of the flux coating is to provide a gas stream to shield the molten weld pool from atmospheric oxygen, hydrogen, and nitrogen contamination until it solidifies. But the coating also:

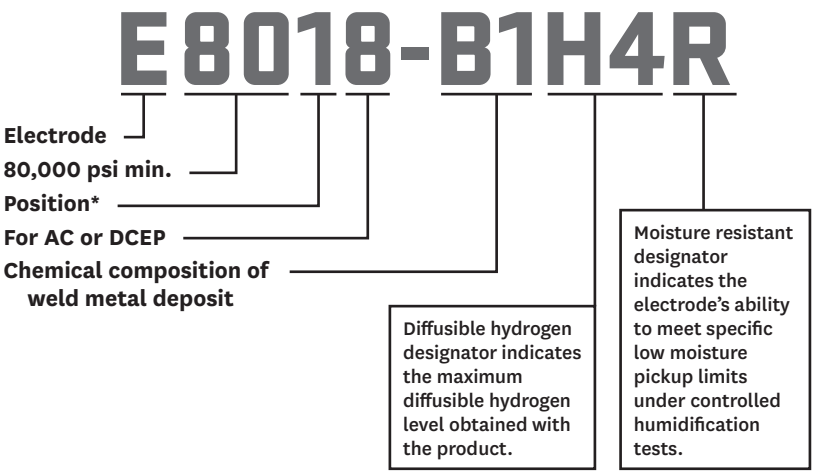
- Supplies scavengers, deoxidizers, and fluxing agents to clean the weld and prevent excessive grain growth (crystallization) in the weld material
- Provides chemicals to the arc that control the electrical characteristics of the electrode, including current type, polarity, and current level
- Covers the finished weld with slag, a protective covering to control weld cooling rate, protect the cooling materials of the weld from the atmosphere, and control bead shape
- Adds alloying materials to the weld pool to enhance weld properties

STICK WELDING ELECTRODE CLASSIFICATION

The American National Standards Institute (ANSI) classifies electrodes in collaboration with the American Welding Society (AWS) and the American Society of Mechanical Engineers (ASME). Both provide convenient and effective ways of choosing welding electrodes for carbon steel. But it is important to check the electrode manufacturer's specifications as well.

THE ANSI/AWS SYSTEM. Electrodes for carbon and low-alloy steel have the ANSI/AWS classification number stamped directly on the flux of the electrode in one or more places. The practice of color-coding SMAW *coated* electrodes is obsolete, but uncoated electrodes used for surfacing are still color-coded. Some manufacturers use color codes to identify their electrodes, and the codes




E 8018-B1H4R
Electrode
80,000 psi min.
Position*
For AC or DCEP
Chemical composition of weld metal deposit
Diffusible hydrogen designator indicates the maximum diffusible hydrogen level obtained with the product.
Moisture resistant designator indicates the electrode's ability to meet specific low moisture pickup limits under controlled humidification tests.

*Position

1. Flat, horizontal, vertical, overhead
2. Flat and horizontal only
3. Number 3 position is not designated
4. Flat, horizontal, vertical-down, overhead

▲ The coding used in AWS electrode classification system for carbon and low-alloy steel electrodes

are explained in their data sheets. ANSI/AWS classifies electrodes used for welding other metals but under different specifications. Again, when in doubt, check the manufacturer's data sheets.

The tables on pages 106–109 describe the electrode classifications systems of AWS — both the coding found on electrodes and the characteristics of each electrode classification.

Types of Electrode Coating and Current

Digit	Type of Coating	Welding Current
0	Cellulose, sodium	DCEP
1	Cellulose, potassium	AC, DCEP, or DCEN
2	Titania, sodium	AC or DCEN
3	Titania, potassium	AC or DCEP
4	Iron powder, titania	AC, DCEP, or DCEN
5	Low-hydrogen, sodium	DCEP
6	Low-hydrogen, potassium	AC or DCEP
7	Iron powder, iron oxide	AC, DCEP, or DCEN
8	Low-hydrogen, iron powder	AC or DCEP

DCEP - Direct Current Electrode Positive
DCEN - Direct Current Electrode Negative

Chemical Composition of Weld Deposit

Suffix	%Mn	%Ni	%Cr	%Mo	%V
A1				½	
B1			½	½	
B2			1–¼	½	
B3			2–¼	1	
C1		2–½			
C2		3–¼			
C3		1	0.15	0.35	
D1 & D2	1.25–2.0			0.25–0.45	
G*		0.50	0.30 min	0.20 min	0.10 min

***Only one of the listed elements required.**

Characteristics of AWS Electrode Classifications

AWS Class	ASME System	Current and Polarity	Welding Positions	Type of Coating
EXX10	F-3	DC, electrode positive	All	High-cellulose, sodium
EXX11	F-3	AC or DC, electrode positive	All	High-cellulose, potassium
EXX12	F-2	AC or DC, electrode negative	All	High-titania, sodium
EXX13	F-2	AC or DC, either polarity	All	High-titania, potassium
EXX14	F-2	DC, either polarity or AC	All	Iron powder, titania
EXX15	F-4	DC, electrode positive	All	Low-hydrogen, sodium
EXX16	F-4	AC or DC, electrode positive	All	Low-hydrogen, potassium
EXX18	F-4	DC, electrode positive or AC	All	Low-hydrogen, potassium, iron powder
EXX20	F-1	DCEN or AC for horizontal fillets; DC, either polarity, or AC for flat work	Horizontal fillets and flat	High-iron oxide
EXX22	F-1	DC, either polarity or AC	Horizontal, flat	High-iron oxide
EXX24	F-1	AC or DC, either polarity	Horizontal fillets and flat	Iron powder, titania
EXX27	F-1	AC or DC, electrode negative	Horizontal fillets and flat	High-iron oxide, iron powder
EXX28	F-1	AC or DC, electrode positive	Horizontal fillets and flat	Low-hydrogen, potassium, iron powder
EXX48	F-4	AC or DC, electrode positive	Flat, horizontal, vertical-down, and overhead	Low-hydrogen, potassium, iron powder

Type of Arc	Degree of Penetration	Surface Appearance	Type of Slag	Character of Slag
Digging	Deep	Flat, wavy	Organic	Thin
Digging	Deep	Flat, wavy	Organic	Thin
Medium	Medium	Convex, rippled	Rutile	Thick
Soft	Shallow	Flat or concave, smooth ripple	Rutile	Medium
Soft	Medium	Flat, slightly convex, smooth ripple	Rutile	Easily removed
Medium	Medium	Flat, wavy	Low-hydrogen	Medium
Medium	Medium	Flat, wavy	Low-hydrogen	Medium
Medium	Shallow	Flat, smooth, fine ripple	Low-hydrogen	Medium
Digging	Medium	Flat or concave, smooth	Mineral	Thick
Soft, smooth	Medium	Flat or slightly convex	Mineral	Medium
Soft	Shallow	Slightly convex, very smooth, fine ripple	Rutile	Thick
Soft	Medium	Flat to slightly concave, smooth, fine ripple	Mineral	Thick
Medium	Shallow	Flat, smooth, fine ripple	Low-hydrogen	Medium
Soft	Shallow	Concave, smooth	Low-hydrogen	Thin

THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS (ASME) ELECTRODE CLASSIFICATION SYSTEM

ASME classifies coated electrodes for carbon and mild steel work in four groups:

F-1 High Deposition Group (also called *Fast-Fill*)

F-2 Mild Penetration Group (also called *Fill-Freeze*)

F-3 Deep Penetration Group (also called *Fast-Freeze*)

F-4 Low-Hydrogen Group

F-1 HIGH DEPOSITION GROUP

- Electrode coating contains 50 percent iron powder by weight, so these electrodes produce a higher weld deposition per electrode than any members of the other groups
- Dense slag and slow cooling make this group useful only for flat and horizontal fillet
- Produces smooth, ripple-free bead with little spatter
- Heavy slag produced is easily removed

F-2 MILD PENETRATION GROUP

- Electrodes have a titania, rutile, or lime-based coating, which aids in the fast freezing required for vertical and overhead welds
- Excellent for welding sheet steel under 3⁄16 inch thick where high-speed, continuous travel with undercutting penetration is required; often used with DCEN

F-3 DEEP PENETRATION GROUP

- Electrodes have a high-cellulose coating that produces deep penetration and a forceful arc; they may also contain iron powder, rutile, and potassium
- Weld solidifies rapidly for use in all positions
- Excellent for welding mild steel in fabrication and maintenance work
- Best choice on dirty, painted, or greasy metal
- Light slag
- Especially good for vertical-up, vertical-down, and overhead and open root welding

F-4 LOW-HYDROGEN GROUP

- Resistance to cold cracking in medium- to high-carbon steels, hot cracking in phosphorus-bearing steels, and porosity in sulfur-bearing steels
- Produces high-quality welds with excellent mechanical properties
- Less preheat than other electrodes
- Reduced likelihood of under-bead and micro-cracking of high-carbon and low-alloy steels and on thick weldments (an assembly of parts joined by welding)
- Can produce excellent multiple-pass, vertical, and overhead welds in carbon steel plate
- Best choice for galvanized metal

Selecting Electrodes

This is not a simple decision, since there are trade-offs between speed, total welding cost, and weld strength. Electrode selection is a matter of matching the operating characteristics of the electrode to the job requirements as well as to the possible need for low-hydrogen electrodes. In general, the electrode rod steel should have the same or higher tensile strength as the base metal and similar chemical properties. Here are the major factors involved in the selection:

- Welder's skill and frequency of welding projects
- Properties and cleanliness of the base metal
- Position of the weld joint
- Type of joint and metal thickness
- Type of power supply
- Tightness of the joint fit
- Total amount of welding needed
- Rod storage limitations (moisture), and capacity for storing many types/sizes

PROPER STORAGE FOR ELECTRODES

Electrodes for shielded metal arc welding (SMAW) must be stored in dry, sealed containers. If you notice deterioration in weld quality (usually cracking) it may be that your electrode has absorbed too much moisture. If you are working in wet conditions, consider using electrodes with an "R" suffix, indicating resistance to moisture absorption.

Storing electrodes inappropriately can ultimately affect the quality of your weld. Water absorbed out of the atmosphere by the flux on low-hydrogen electrodes will introduce hydrogen into the weld, causing cracking and brittleness. Dry electrodes can take from 30 minutes to 4 hours to pick up enough water (and the water's hydrogen) to adversely affect weld quality. For this reason, professional welding shops keep low-hydrogen electrodes (after removing them from sealed electrode dispensers) in drying ovens until they are used. This option is usually not available to the home welder. If you're using this type of electrode, check the manufacturer's data sheets for instructions on handling the electrodes.

Electrodes should always be stored in dry, sealed containers.

DETERMINING ELECTRODE SIZE

The best choice of electrode is the one that produces the weld required in the least amount of time. Usually larger-diameter electrodes are used for thicker materials and flat welds where their high deposition rates can be an advantage. In nonhorizontal positions, smaller electrodes are used to reduce the weld pool size, as gravitational forces are a factor working against the welder's skill.

Other variables to consider include:

- Joint thickness and heat range required
- Welding position
- Type of joint
- Welder's skill

COMMON DIMENSIONS OF SMAW ELECTRODES

The most common length is 18 inches (460 mm). The common diameters (of the core wire) are, in inches:

1/16 (1.6 mm)	**3/16 (4.8 mm)**
3/32 (2.4 mm)	**7/32 (5.6 mm)**
1/8 (3.2 mm)	**1/4 (6.4 mm)**
5/32 (4 mm)	**5/16 (7.9 mm)**

Setting Up Stick Welding Equipment

Compared to other welding processes, stick welding is relatively easy to set up. After all safety precautions have been taken, there are few steps to take before striking the arc and running a weld bead.

1 **Protect your eyes.** Put on your safety glasses, and leave them on for the remainder of the procedure.

2 **Check the power supply.** Locate the welding power supply near the work, and note the location of the AC power shutoff switch in case of emergency. Make sure the welding power supply is grounded. If an engine-generator is the welding power source, locate the engine shutoff switch.

3 **Safeguard the surroundings.** Make sure the areas around the power supply and the work are dry. Remove flammable materials near the spark stream area and confirm that firefighting materials are close at hand.

4 **Choose your electrode.** Select the electrode material and diameter based on the job requirements or drawings. Set them out in your work area.

5 **Set the current.** Set the polarity and the welding current on the power supply. Do not make adjustments while welding.

6 **Attach the cables.** Stretch out the welding cables, and attach the work lead to the work securely; clean the grounding area, if necessary.

7 **Suit up for safety.** Put on your welding safety equipment (helmet, cap, gloves, leathers); keep your safety glasses on under your welding helmet.

8 **Get started.** Turn on the welding machine, insert the electrode in the holder, drop your welding helmet, strike the arc, and begin welding.

STRIKING THE ARC

TWO WAYS TO START. Welding with AC usually calls for a *scratch-start*: Tilt the electrode about 15 degrees in the direction of travel and, while drawing the electrode above the work as if striking a match, allow it to momentarily touch the work; this strikes the arc. Withdraw the electrode above the work to a height equal to its own diameter.

Welding with DC usually calls for a *tapping-start*: Lower the electrode quickly until an arc forms, then raise the electrode above the work to a height equal to its own diameter.

RESTARTING AN ARC ON AN EXISTING WELD. Strike an arc about 1 inch further along the weld path than the interrupted weld bead. Then, carry the arc back to the previous stopping point and begin welding again. The new weld bead will cover and eliminate the marks of the strike.

Determining Work and Travel Angle

The joint type and welding position determine the travel angle of the electrode.

Type of Joint	Welding Position	Working Angle	Travel Angle	Technique of Welding
Groove	Flat	90°	5–10°*	Backhand
Groove	Horizontal	80–100°	5–10°	Backhand
Groove	Vertical-Up	90°	5–10°	Forehand
Groove	Overhead	90°	5–10°	Backhand
Fillet	Horizontal	45°	5–10°*	Backhand
Fillet	Vertical-Up	35–45°	5–10°	Forehand
Fillet	Overhead	30–45°	5–10°	Backhand

***Travel angle may be 10–30° for electrodes with heavy iron castings.**

Choosing the Right Filter Plate Shade Number, Based on Electrode Diameter

Be sure your helmet is outfitted with the correct filter plate before stick welding. The shade of the filter lens depends on the arc current and the electrode diameter.

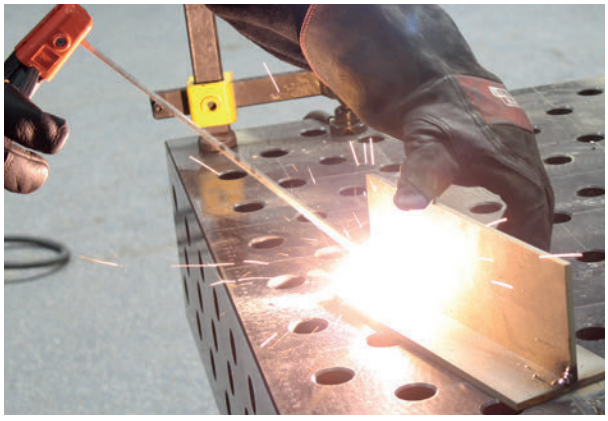
Welding Electrode Diameter (inches)	Welding Electrode Diameter (mm)	Filter Plate Shade Number
Up to 5/32	Up to 4	10
3/16–1/4	4.8–6.4	12
Over 1/4	Over 6.4	14

Stick Welding Tips

Stick welding is often referred to as arc welding, which can be confusing for the novice because all modern welding techniques employ an electric arc to produce the heat necessary to fuse metal. Stick, or shielded metal arc welding, was one of the first and the name has stuck with the process.

With the polarity and current set on the welding machine, make sure the work lead (ground cable) clamp is secured to the workpiece or welding table.

Clamp the electrode into position. Keep extra electrodes handy, because they are consumed quickly. Depending on the type of joint, you won't be able to weld much more than 8 to 10 inches with each electrode.



When starting a bead, circle the rod a few times at your start point. This heats up the metal and allows a weld pool to form. You can either push or pull the electrode when welding, depending on the desired heat or penetration. Experiment with both. When welding, maintain a constant arc length, which is the distance between the electrode and the work. The length should be slightly smaller than the diameter of the electrode you are using, up to 1/8 inch.

What you see on this tack weld is slag that covers the weld. The slag protects the weld from impurities while it is fusing the metal together. Remove the slag with a chipping hammer and follow with a wire brush, if necessary. When restarting a weld, chip away some of the slag at the end of the previous section. Then, restart a little ahead of the finished area and work back to tie the two sections together.

USING SMAW FOR CUTTING

If necessary, SMAW can be utilized for cutting metals, though it's not as clean or efficient as oxyacetylene cutting. Select a high-penetration cellulose rod, such as a 6011. If you will be cutting a lot, you can wet the rod(s) — only for cutting purposes — to make the rod(s) run cooler and last longer. Set the welder to AC and at a high amperage range for the rod diameter. Using the same welding helmet and equipment for SMAW, strike an arc where you will be cutting. Starting at the edge or a corner on the edge, create a weld puddle, then use a sawing motion to push the weld puddle through and out the bottom. Continue this slow up-and-down motion down the cutting line.

BUILDING A BETTER TRACTOR BUCKET

A front-end tractor loader is one of the most useful pieces of equipment on the farm or ranch. However, a couple of simple welding projects can add greater utility at a minimal cost.

Adding Flat-Backed Hooks

Welding hooks to your tractor bucket allows you to hoist objects that don't easily fit in the bucket. The hooks we used for this project are 5⁄16-inch grab hooks, meaning that they're sized for 5⁄16-inch chain. The back of the hook is flat, creating more surface area, which will result in a stronger weld.

1

Remove the bucket from the tractor to reduce the risk of damaging hydraulic lines that may be in close proximity to the welding area. Begin by marking out the desired location for the hooks and grinding the surface clean.

2

We opted to place one hook on each side of the bucket for enhanced versatility. If you only mount a single hook, mount it in the center. Consider using a clamp to keep the hook from moving during the tack welding process. As you become more experienced, you may find clamping to be unnecessary as you become more aware of the electrode location.

3

Tack weld each end of the hook and confirm proper hook placement. You will also notice that while the back (bottom) of the hook is flat, the sides have a bevel groove on the inside corner which creates a stronger, deeper penetrating weld.

4

Properly positioning both your body and the electrode in the holder creates a more effective angle for pushing the electrode into the groove, thereby creating a stronger weld.

5

We made a total of four passes on each side of the hook, alternating side to side and removing the slag after each pass. The final weld is free of air pockets and has solid penetration on both the hook and the bucket.

Adding a Bale Spear

A variety of manufacturers offer weld-on bale spear kits that can be mounted to a tractor bucket. The simplest arrangement consists of a weldable sleeve that holds the bale spear. The technique used for attaching the bale spear is very similar to welding flat-backed hooks. The one notable exception is that because the sleeve is round, and the butting surfaces are square, a multiple-pass technique is used that alternates each pass from side to side (see page 25).

A gusset in the top of the tractor bucket provided a strong corner that we were able to use as a mounting point. With both the mounting surface and the sleeve ground clean, a tack weld was made in each corner, alternating side to side.

2

Alternate sides as you run each bead of weld. Allow the weld to cool before removing the slag with a chipping hammer.

3

After six passes on each side the bale spear sleeve is securely mounted and ready for use.

HAYWAGON STEERING REPAIR

This haywagon repair was temporarily functional, but unfortunately it was welded in such a position that the front wheels weren't parallel, thus creating excessive damage to the wheel bearing. We opted to cut out a section of the tie rod and replace it with new 1.5 × 16-inch flat steel stock that returned the wheels to their original geometry.

To remove the old section you could use a variety of tools including oxyacetylene cutting torch, grinder with cutting wheel, or even a DC+ arc welder. We opted to demonstrate using the arc welder technique. The trick is to use a small diameter (we used 3⁄32 inch) 6011 rod and 85–90 amps to blow through the metal. While the cut is somewhat crude, it's effective for a field repair when equipment is limited.

Use welding clamps to secure your new tie rod and tack weld. Confirm that the wheel geometry is correct before proceeding.

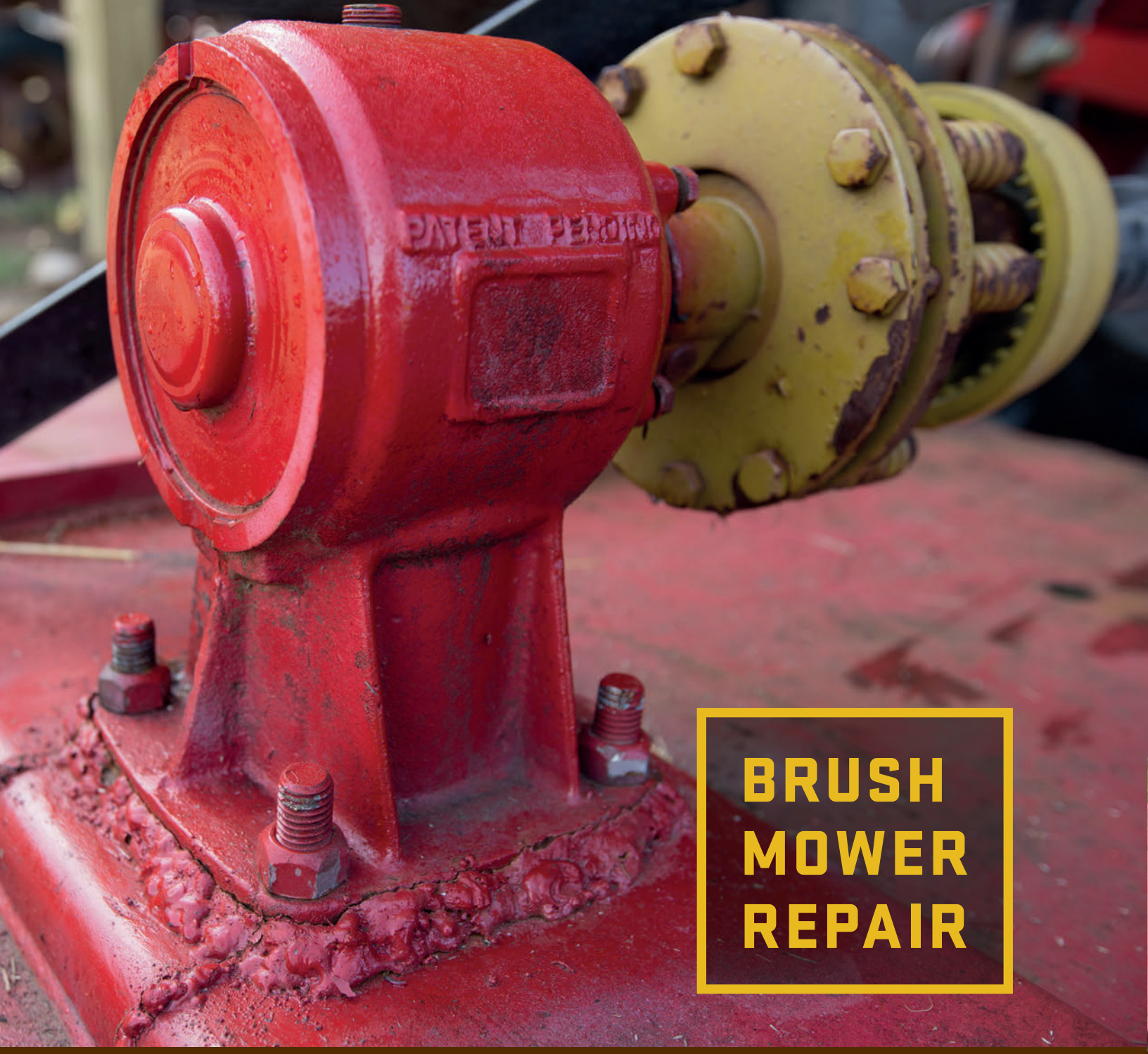
3

Since a hole already existed, we were able to use a plug weld that joined the metal together in the center, instead of the edges. Since we initially welded the edges, using a plug weld in the center of the tie rod made it exceptionally strong.

4

A fillet weld on the opposite side rounds out this repair and puts this hay wagon back into service.

The repaired haywagon is back in service.



BRUSH MOWER REPAIR

The gear box on this brush mower wore loose and the owner continued to use it. The result was that the gear box tore out of the mounting holes. The owner attempted to weld the cast iron gear box to the steel deck, which did not hold since they are dissimilar metals. Note the excessive amount of weld around the base. To repair this we removed the gear box and created a new mounting plate.

1

Once we removed the gear box, we ground away the existing weld with an angle grinder to create a smooth, workable surface. Note that the mounting holes are cracked and elongated.

2

We used a ¼-inch-thick 8 × 16-inch mild steel plate for the repair. We marked the template with a soapstone pencil by holding it to the topside of the mower and marking from the underside.

3

We then cut the holes using an oxyacetylene torch over a metal trash can to catch the hot pieces.

4

A dry fit over the gear box confirms that all the holes align. Note that the corners of the repair plate are rounded. Avoiding corners distributes the stress more evenly.

5

The plate is welded in position using a chain intermittent fillet weld, which is strong, flexible, and is faster to complete than a continuous weld.

Good as new! This brush mower is ready to be returned to service.

SIX

WIRE-FEED WELDING PROCESSES

MIG WELDING AND FLUX-CORED ARC WELDING

Wire-feed welding is most commonly known as MIG, for metal inert gas, but its official designation is Gas metal arc welding (GMAW). In this process, the welding equipment continuously feeds a wire electrode to the welding gun. As the electrode is consumed during the course of the weld, new wire takes its place. A shielding gas, also dispensed through the welding gun, keeps the weld free of impurities that could weaken it. Flux-cored arc welding (FCAW) is a similar process, but rather than use a shielding gas, the electrodes consist of a thin-walled tube filled with flux, which protects the weld. Each process is discussed in this chapter.

How the MIG Process Works

The welder positions the electrode wire coming from the center of the nozzle to where the weld is to begin, actually touching the welding wire to the base metal. When the welder drops his hood and squeezes the trigger on the welding gun, three events happen simultaneously:

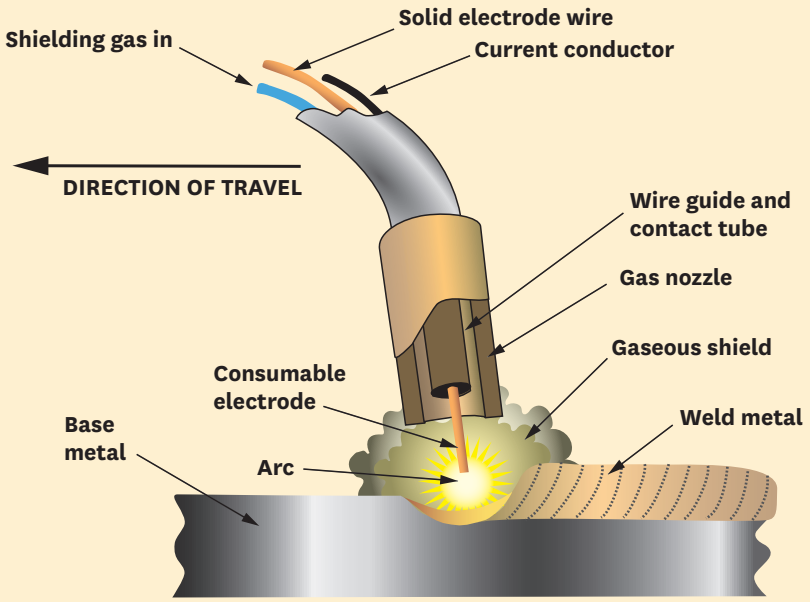
- The trigger turns on the welding power supply; welding cable conductors feeding the gun apply voltage to the copper contact tip within the gun, and then to the electrode wire, striking the arc.
- The wire-feed mechanism begins feeding the welding wire from the spool through the welding gun cable, out through the contact tip, and into the weld pool. Note that the welding gun cable is really a bundle of cables: power cables, control cables, electrode wire liner, shielding gas line, and, possibly, cooling water and smoke extractor lines.
- An electrically operated valve (solenoid) opens and feeds shielding gas from the regulator/flow meter to surround the electrode and weld pool, shielding them from the atmosphere, particularly oxygen and nitrogen.

Welding begins as the section of electrode wire between the tip of the electrode and the base metal is heated and deposited into the weld. As the wire is consumed, the feed mechanism supplies more electrode wire at the preset rate to maintain a steady arc. The welder manipulates the gun and lays down the weld in the desired pattern.

To stop the process when the weld is completed, the welder releases the trigger, shutting off the welding current, wire feed, and shielding gas.

MIG Welding

Here's a close-up look at the MIG welding process in action. The wire electrode is continuously fed through the contact tube, creating a continuous arc that melts the base metal and the wire electrode itself. Gas from the nozzle shields the weld from atmosphere.



PROS AND CONS OF THE MIG PROCESS

ADVANTAGES

- The only consumable process that can weld most commercial alloys, including aluminum, carbon steel, copper, low-alloy steels, magnesium, nickel, stainless steels, and titanium
- MIG welding, with its continuous wire electrode, avoids the start-and-stop cycle of SMAW and leads to fewer discontinuities and higher deposition rates
- No need to stop welding to change consumed electrodes, so long continuous welds can be done manually
- All welding positions can be used, employing the short-circuit transfer mode
- Significantly higher utilization of filler metal than SMAW; there is no end loss, as with the upper, unconsumed end of an SMAW electrode
- Deeper penetration with higher deposition than SMAW and may permit smaller fillets of the same strength
- Metals as thin as 24 gauge (0.023 inch) may be welded, using a thinner consumable electrode
- Easier to learn than most other welding processes
- No practical thickness limitations
- Very little spatter and no slag with properly adjusted equipment; many manufacturers paint or plate over MIG welds with little or no additional surface preparation
- Significantly less smoke than SMAW, if using a shielding gas without flux

DISADVANTAGES

- Welding equipment can be more expensive, more complicated, and slightly less portable than SMAW
- MIG welding can be difficult to use in tight quarters, as the gun is large and the gun cable is somewhat stiff and inflexible
- Large size of the MIG gun, combined with the ½- to 1-inch stickout of the electrode wire, makes it harder to see the arc and achieve quality welds
- Outdoor use is limited to very calm days or where shielding screens can be used to prevent the shielding gas from being blown away; MIG cannot be performed outdoors in greater than a 5 mph breeze
- Without flux, the metal to be welded must be very clean

MIG WELDING SAFETY

PROTECT YOUR EYES AND FACE. The total radiated energy, both visible and invisible, of MIG is much higher than SMAW processes due to less smoke, so extra precautions must be taken to protect the eyes and skin. Protect your face and eyes from sparks and radiation with a helmet and lens of an appropriate density number. The heat of MIG welding can be great enough to crack a filter lens. For this reason, all welding masks should have an appropriate glass or plastic filter cover both in front of and behind the welding glass filter. Use the table below to determine the filter glass shade to use with MIG welding; try the darker shade for the current you are using, and drop to the next lighter shade until you can see the welding action clearly. Never drop to a shade lighter than the lowest recommended one.

PROTECT YOUR SKIN. Protect your skin from ultra-violet, invisible radiation with dark leather or wool clothing. Pay particular attention to both the direct and reflected light from the arc on your arms (cover them with a shirt or leathers), neck area (add a commercially available leather flap to the bottom of your welding helmet), and the top of your head (wear a welder's cap).

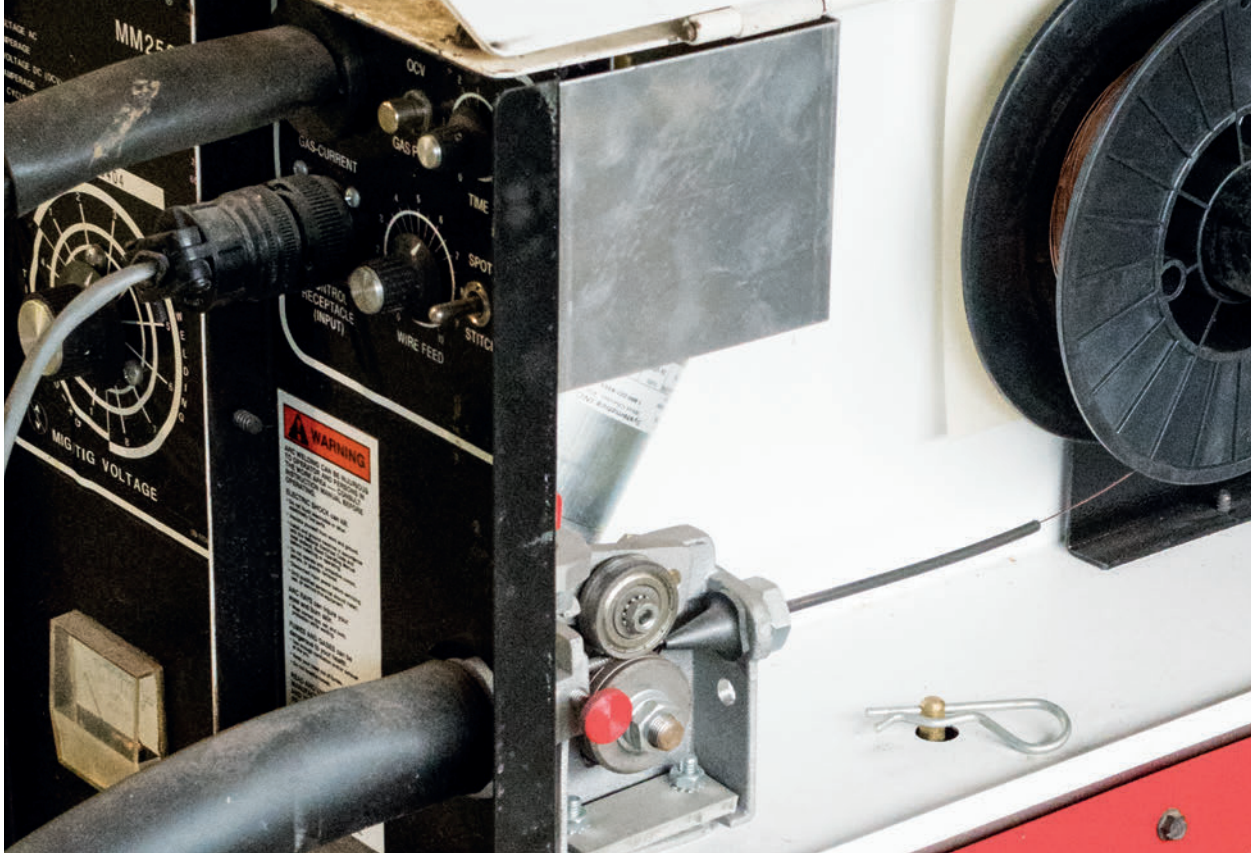
PROTECT YOUR EARS. MIG welding can be a noisy process, and hearing protection may be necessary for both comfort and safety. Continuous exposure to relatively low noise levels (especially high frequencies) can cause permanent hearing loss. Ear plugs and ear muffs may be needed.

Lens shade selection chart for GMAW and FCAW

Welding Current (in amperes)	Minimum Protective Shade	Suggested Shade for Comfort
> 60	7	8
60–160	10	11
160–250	10	12
250–500	10	14

▲ Modern MIG welding setups comprise a constant-voltage (CV) welding power supply, a wire feeder (containing wire-feed motor, spool support, wire-feed drive rolls, and associated electronics), the welding gun and its cable, the work lead clamp, work lead (cable), and its terminals, welding wire, a flow regulator or flow meter for shielding gas, and a compressed gas cylinder.

► A modern, portable welder makes it easy to set up an accessible, temporary, outdoor work station.



ADJUSTABLE WIRE SPEED AND VOLTAGE

Finding the right wire speed and voltage for the right metal thickness and welding position is necessary to produce a strong weld. You can refer to user data sheets for the specific welder you are using, or gain experience through trial and error.

DCEP (direct current electrode positive) is always used with MIG welding. This is because the three metal transfer modes that actually move metal ions through the arc (short-circuit, globular, and spray transfer modes) move positively charged metal ions. These positive ions must travel through a positive to negative voltage field — just what DCEP provides.

ARC VOLTAGE. The best way to set arc voltage is to begin at the recommended voltage based on welding tables from AWS or the electrode manufacturer's data sheets. The base metal, type of metal transfer, and shielding gas provide a starting point; exact refinement will come from several trial runs.

The goal is to control arc length, but because this is hard to measure, and arc length is closely related to arc voltage, we choose to control arc voltage instead. Most welding specifications indicate arc voltage setting, not arc length. This is because with all other variables held constant, arc length is proportional to arc voltage. Arc voltage depends on materials welded, shielding gas, and metal transfer mode.

AMPERAGE. Welding current (amperage) is determined by the wire feed rate, which is the speed the electrode emerges from the welding gun and is usually marked on the speed control or digital readout. The higher the electrode wire feed rate, the more current the constant-voltage welding power supply must provide. The welding current on a constant-voltage power supply cannot be directly adjusted. With all other welding variables held constant, an increase in wire feed speed (and thus welding current) will:

- Increase depth and width of weld penetration
- Increase deposition rate
- Increase weld bead size

How to Select MIG Electrodes or Welding Wire

MIG electrodes are usually solid, bare wire similar in composition to the base metal being welded. Some electrode wire for welding ferrous metals has a thin copper plating to facilitate the drawing of the wire when it is made at the factory. Some wire manufacturers would have you believe this coating is added to prevent rust and to make the wire run better; it is not.

Silicon is also added to maintain metal integrity at high arc temperatures. As an aggressive scavenger, it combines with unwanted elements and forms a glaze on the weld surface. It pops off when cool and is another reason to wear safety glasses at all times.

COMMON DIMENSIONS OF MIG ELECTRODE WIRES

The common diameters in inches:

0.020	**0.125 (or 1/8)**
0.025	**0.188 (or 3/16)**
0.030	**0.250 (or 1/4)**
0.035	**0.313 (or 5/16)**
0.045	**0.375 (or 3/8)**
0.062 (or 1/16)	**0.500 (or 1/2)**
0.094 (or 3/32)	

WIRE FEED RATE AND WELD DEPOSITION RATE

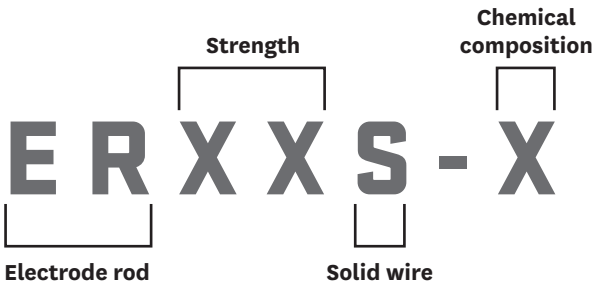
Again, the wire feed rate is the speed at which the electrode wire emerges from the welding gun. It is measured in inches/second, or pounds/hour. The deposition rate is the weight of welding wire going into the weld. It is nearly always less than the wire feed rate. The difference between the two is the result of slag, spatter, or fumes from the electrode wire. The deposition efficiency is the ratio of the weld deposition rate to the wire feed rate. MIG with an argon shielding gas can reach 98 percent deposition efficiency.

MIG welding wire is made from steel with a copper coating that aids in lubricating the wire as it moves from the spool to the MIG welding gun and out of the contact tip.

IDENTIFYING MIG WELDING WIRE

The American Welding Society's MIG electrode identification system is shown in the table below. "ER" designates the wire as being both an electrode and a rod, meaning it may conduct electricity (electrode) or simply be applied as a filler metal (rod) when used with the MIG process. The characteristics of the most common MIG electrodes for carbon steel meeting AWS/ASTM specifications are shown below.

AWS MIG ELECTRODE IDENTIFICATION SYSTEM



MIG Electrode Wires for Mild Steel

AWS Designation	Characteristics	Shielding Gas(es)
ER70S-2	Contains deoxidizers that permit welding on thin rust coatings. Can weld in any position. Excellent for out-of-position short-circuit welding. Makes excellent welds in all mild steels.	Ar-O_2 Ar-CO_2 CO_2
ER70S-3	Single or multipass beads. Base metal must be clean. Preferred for galvanized metals. Used on autos, farm equipment, and home appliances. Has better wetting action and flatter beads than E70S-2.	Ar-CO_2 CO_2
ER70S-4	Used for structural steels like A7 and A36. Used for both short-circuit and spray. Used in ship building, pipe welding, and pressure vessels. Flatter and wider beads than E70S-3.	Ar-O_2 Ar-CO_2 CO_2
ER70S-5	Used on rusty steel. Not recommended for short-circuit transfer mode. Flat position only.	Ar-O_2 Ar-CO_2 CO_2
ER70S-6	General-purpose wire used on sheet metal. Will weld through thin rust. Welds all positions. Used with high welding currents.	Ar-O_2 Ar-CO_2 CO_2
ER70S-7	Used on heavy equipment and farm implements. Welds in all positions.	Ar-CO_2 CO_2

Ar = Argon **CO_2 = Carbon dioxide** **O_2 = Oxygen**

ADDITIONAL EQUIPMENT

Aside from the basic setup, there is other equipment available for MIG welders that can add efficiency and safety. Two of the more common accessories are a water cooler and a smoke evacuator.

A water cooler is used when MIG and FCAW welding guns are operated continuously at high amperage levels and get so hot they literally melt the gun from the heat of the weld and the heat from the nozzle tip. This situation occurs during spray-metal transfer. The solution is to feed cooling water into the nozzle to keep its temperature down. The hot water from the tip is then recirculated back to the water cooler and used again. The water cooler consists of a pump, fan, and internal spray, much like an evaporative cooler. Alternatively, city water may be used to cool the welding gun and then discharged into a drain; this approach eliminates the need for a water cooler.

A smoke evacuator system, built in to a MIG or FCAW welding gun, is for capturing and removing welding smoke at the nozzle of the welding gun. The smoke reduction adds to welder safety, comfort, and visibility, but the evacuator also adds weight to the gun and stiffness to the welding cable.

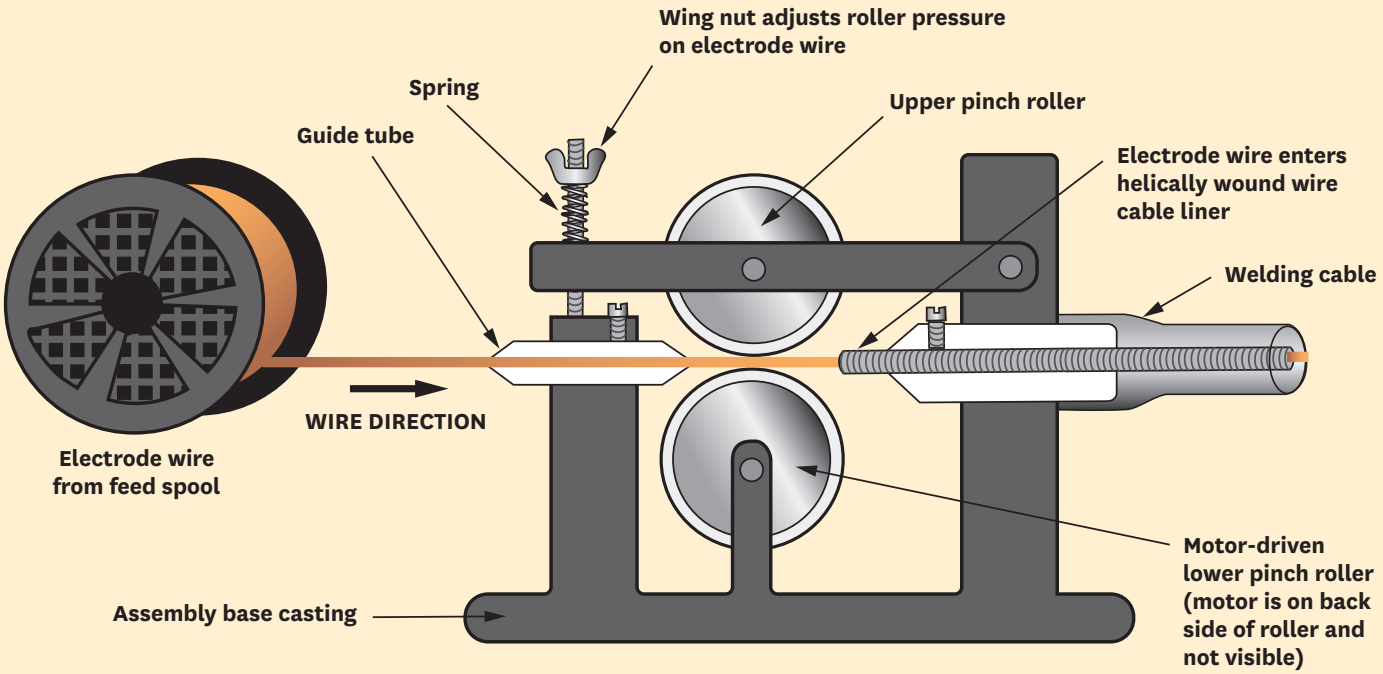
MOVING THE ELECTRODE

The following are the three most common methods of moving electrode wire from the spool to the welding area.

- **DRIVE WHEELS IN THE WIRE-FEED MECHANISM** One or more pairs of drive wheels in the wire-feed mechanism grip the electrode wire and push it through the wire-feed tube to the

MIG Wire-Feed Mechanism

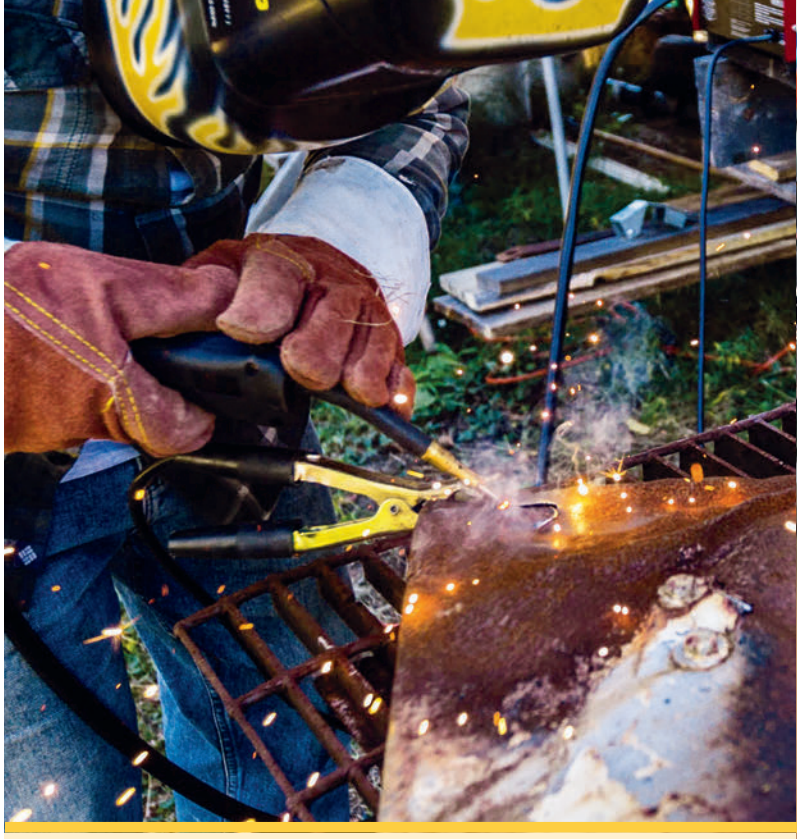
This is a typical wire-feed mechanism using drive wheels, found inside of a MIG welder. The drive wheels pull the wire off the spool and push it through to the welding gun.


Wing nut adjusts roller pressure on electrode wire
Spring
Upper pinch roller
Guide tube
Electrode wire enters helically wound wire cable liner
Welding cable
WIRE DIRECTION
Electrode wire from feed spool
Motor-driven lower pinch roller (motor is on back side of roller and not visible)
Assembly base casting

welding gun. This is by far the most common arrangement and works well except when using very soft electrodes, like aluminum. Whereas older MIG setups had a wire feeder separate from the power source, in current models the wire spool and wire-feed mechanism are in the same housing as the power source, accessible through a side door on the welding machine.

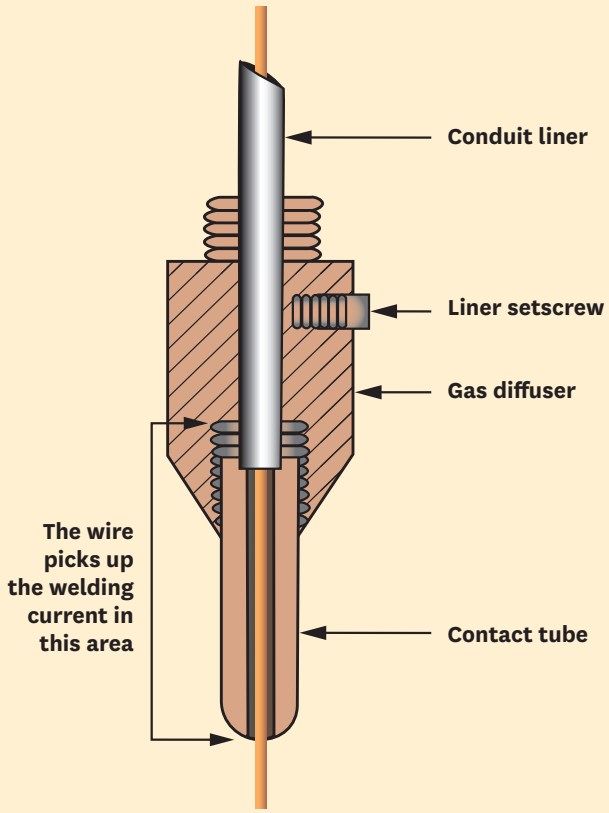
- **SPOOL GUN/TORCH.** The torch assembly contains both a small spool of electrode wire and a DC motor to drive it out through the contact tube. Because of their pulling action, spool guns work well for handling soft wires, like aluminum, or when using thin electrode wire with a long cable assembly. The downside is the increased weight the welder must manipulate.
- **PULL GUN.** The torch assembly contains a small DC motor and drive wheels, which assist in pulling the soft wire through the cable liner and out through the torch tip. This has the advantage of reduced torch weight with the ability to handle soft electrodes.

Spool guns work well for handling soft wire.



MIG Torch Tip Assembly

The welding current travels from the power source down the conduit liner within the welding gun cable. The current is then transferred to the contact tip and delivered to the electrode.



This is a portable MIG setup with shielding gas tank. Shielding gas prevents impurities in the atmosphere from reaching the molten metal of the weld.

The Role of Shielding Gas in the MIG Process

The main function of shielding gas is to prevent atmospheric oxygen and nitrogen from reaching the molten metal of the weld. Most metals in the molten state combine with atmospheric oxygen and nitrogen to form oxides and nitrides. These two classes of compounds can leave the weld with porosity, embrittlement, or trapped slag, greatly impairing its mechanical properties.

Shielding gases may also:

- Stabilize the arc
- Establish the penetration level and weld bead shape
- Enhance welding speed and help cool the gun
- Minimize undercutting
- Remove oil or mill scale just prior to welding
- Control weld metal mechanical properties

SHIELDING GASES USED FOR MIG WELDING

INERT GASES

The following inert gases will not react with other chemical elements.

Argon (Ar). Often used for welding vertically and overhead because of its lower heat conductivity; it is 10 times heavier than helium so it blankets the weld better than helium.

Helium (He). An excellent heat conductor, bringing heat from the arc into the weld area. It is used where high heat input is needed — as in joining thick sections — and when welding copper and aluminum, which are excellent conductors of heat and remove heat rapidly from the welding zone.

REACTIVE GASES

The following reactive gases will form compounds with other chemical elements and are used to achieve specific objectives at low concentrations in GMAW.

Carbon dioxide (CO_2). Results in better metal transfer, lower spatter, more stable arc, and improved flow of metal to reduce undercutting.

Oxygen (O_2). Blended with argon in small percentages to reduce volts.

Hydrogen (H_2). In small percentage concentrations, removes light rust and eliminates surface cleaning.

Nitrogen (N_2). Used on copper.

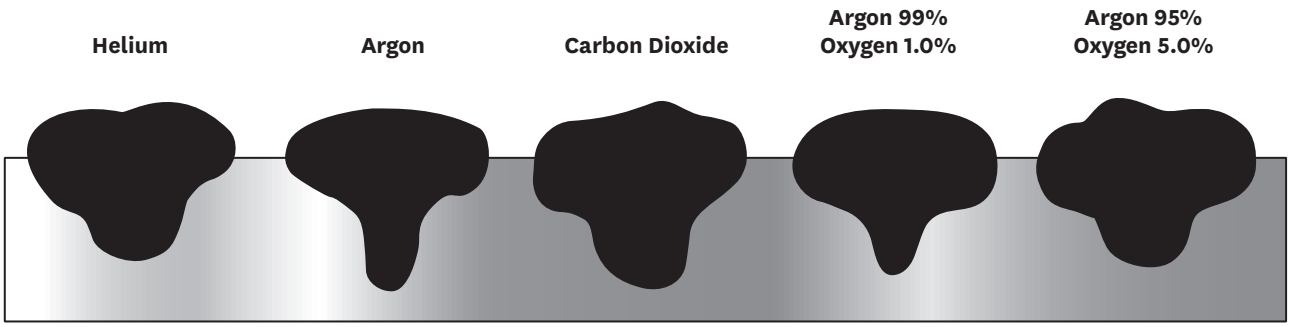
ADVANTAGES OF GAS MIXTURES

Mixtures produce better arc stability, lower spatter, and better bead structure than any one gas used by itself. By mixing gases we can get the best performance properties each component gas can produce. Some common gas mixtures for MIG welding are:

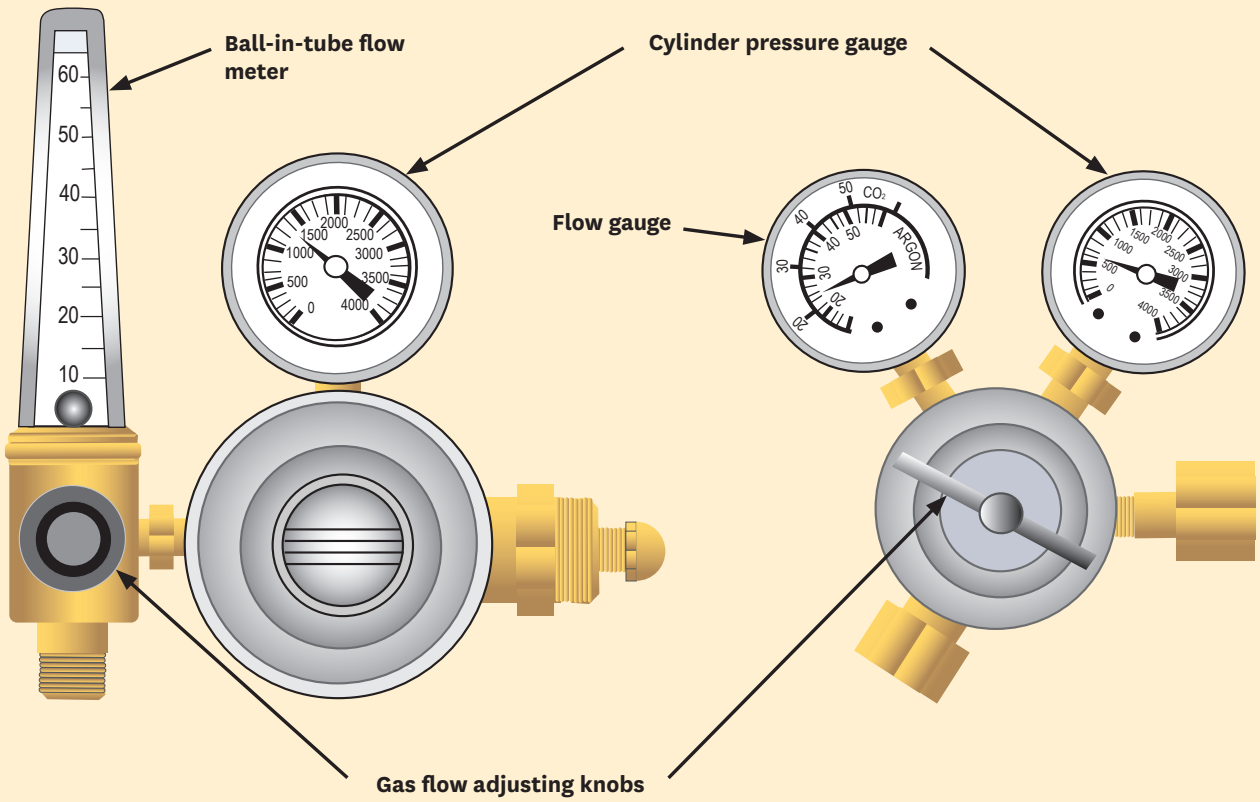
- Argon + Helium
- Argon + Oxygen
- Argon + Carbon dioxide
- Helium + Argon + Carbon dioxide

SHIELDING-GAS METERING SYSTEMS

There are two types of gas metering systems: pressure regulator with high- and low-pressure gauges and pressure regulator with ball-in-tube flow meter.



▲ This cross section shows how weld bead shape and penetration varies with different shielding gases.



The two types of shielding-gas metering systems: regulator with ball-in-tube flow meter (left) and regulator with gauges (right). Both control flow in cubic feet per hour.

TIPS FOR ADJUSTING SHIELDING GAS

- **Adjust gas flow according to either AWS specification or the equipment manufacturer's data sheet. If neither is available, begin at about 20 to 25 cubic feet per hour (9.4 to 11.8 liters per minute); increase the gas flow until visible signs of weld porosity cease.**
- **Getting an effective inert gas shield from the atmosphere depends on both having enough flow and maintaining a laminar (turbulence free) flow. Turbulence from too high of a gas flow rate will introduce contamination into the area you want to shield, ruining the weld. It also wastes shielding gas.**
- **Carbon dioxide is commonly used on mild steel for minimum cost. A mixture of 75 percent argon + 25 percent carbon dioxide (sometimes called C25 mixture) is used for general welding of carbon steel and low-alloy steel with excellent results.**
- **If your welder has a preflow and postflow setting for shielding gas, adjust it according to your conditions. Preflow starts letting out shielding gas slightly before wire feed to purge the weld area of air. Postflow keeps the shielding gas flowing slightly after the weld stops to shield the cooling weld.**
- **In selecting a shielding gas, consider cost, weld appearance, and weld penetration. In some cases, mixes of different gases are best for the job.**

Setting Up MIG Equipment

Taking the time to familiarize yourself with and practice on your new MIG welder before beginning an actual repair or fabrication project is a good idea. MIG welders have adjustable wire speed and voltage settings, controlled with a knobs or dials with digital readouts. Some newer welders even have automatic settings for specific thicknesses of metal. One way to determine your welder's settings is to use the manufacturer's chart that is usually located on the inside of the welder's access door. Using such a chart will give you the general settings for the thickness of metal you are welding and the electrode diameter you are using.

Another way is by trial and error. Adjust your settings to the 12 o'clock position and run a bead on your practice piece. If your wire burns out before penetrating the metal, the voltage is too low. If it burns a hole in the metal, it's too high. Find out the results of diferent wire speeds, too, and learn how to adjust your settings by listening to and recognizing the consistent, crackling sound, like eggs frying, which is the sound of a good MIG weld.

SETUP STEPS

1 Make sure the welding area is dry and free of flammable materials and volatile fumes, and that others present are protected from arc radiation and sparks.

2 Make sure the welding power supply and wire feeder power are turned off. Choose the correct wire type, diameter, contact tip, and the correct shielding gas for the application and the metal to be welded.

3 Mount the electrode wire spool on the wire feeder.

4 Open the feed roller gate — without letting go of the electrode wire (it will uncoil and make a snarl if you do). Insert the wire into

Use MIG pliers or a pair of side cutters to trim the electrode to the proper length before welding.

the feed roller mechanism and into the start of the liner tube. Close the gate to secure the wire. Match the wire feeder rolls to the wire diameter.

5 Turn on the welder's power and hold down the trigger of the welding gun to load the wire into the welding cable liner and up to and through the welding gun.

6 Adjust the feed roller pressure until you can no longer stop the wire from feeding into the rollers by pinching the electrode wire between your thumb and index finger. Erratic wire feeding usually results from too much roller pressure, which causes the electrode wire to flatten (and loose feed) as it passes through the rollers.

7 Confirm that the compressed shielding gas cylinder is properly secured. Crack the valve to remove any dirt. Screw the flow regulator or flow meter (or both) onto the cylinder valve, and secure the other end of the gas line into the welding machine.

8 Press the PURGE button for several seconds to remove air from the lines and fill them with shielding gas. (If there is no PURGE button, squeeze the welding gun button, making sure the gun is not touching anything or anyone.) While performing this purge, set the flow meter or flow regulator for the recommended purge gas flow rate: 20 cubic feet per hour (9.5 liters per minute) for 0.035-inch wire is a good starting point. On larger-diameter electrode wire, begin with 20 cubic feet per hour (9.5 liters per minute) on horizontal and 30 to 35 cubic feet per hour (14 to 16.5 liters per minute) on out-of-position welds.

9 Set the proper polarity (DCRP), voltage, and wire feed speed. Note: Find this information on the manufacturer's data sheets for the electrode wire or on tables attached to the welding machine.

10 Attach the work lead to a clean spot on the work.

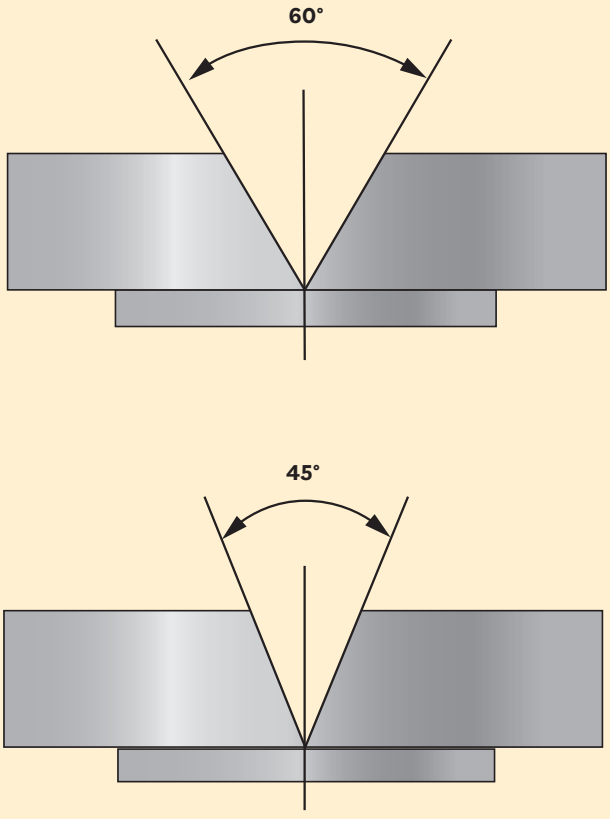
11 Use wire cutters to trim the electrode stickout to the proper length — about ½ inch. Adjust the gas nozzle to stick out slightly beyond the wire contact tube.

12 Put on your welding helmet (keep your safety glasses on under your helmet), position the electrode against the work, squeeze the trigger, and begin welding.

Joint Preparation Steps for MIG Welding

MIG welding thin metals (up to 3⁄16 inch) needs no joint preparation. Metals that are between 3⁄16 inch and 3⁄8 inch can be welded in a single pass if the joint edges are prepared correctly. If the base metal is thicker than 3⁄8 inch, a multipass weld is necessary, as well as the correct joint preparation. With these techniques, there is no limit to the thickness of the metal to be welded.

Because the MIG electrode has a smaller diameter than the SMAW (stick welding) electrode, it can get to the bottom of a narrower V-groove. Therefore, the preparation for V-grooves may be made to a smaller angle. This saves as much as 50 percent on welding filler metal and welding time. It is acceptable to use a SMAW V-groove design for MIG; it will just take longer than necessary.



V-groove joint for stick welding (top) and MIG welding (bottom)

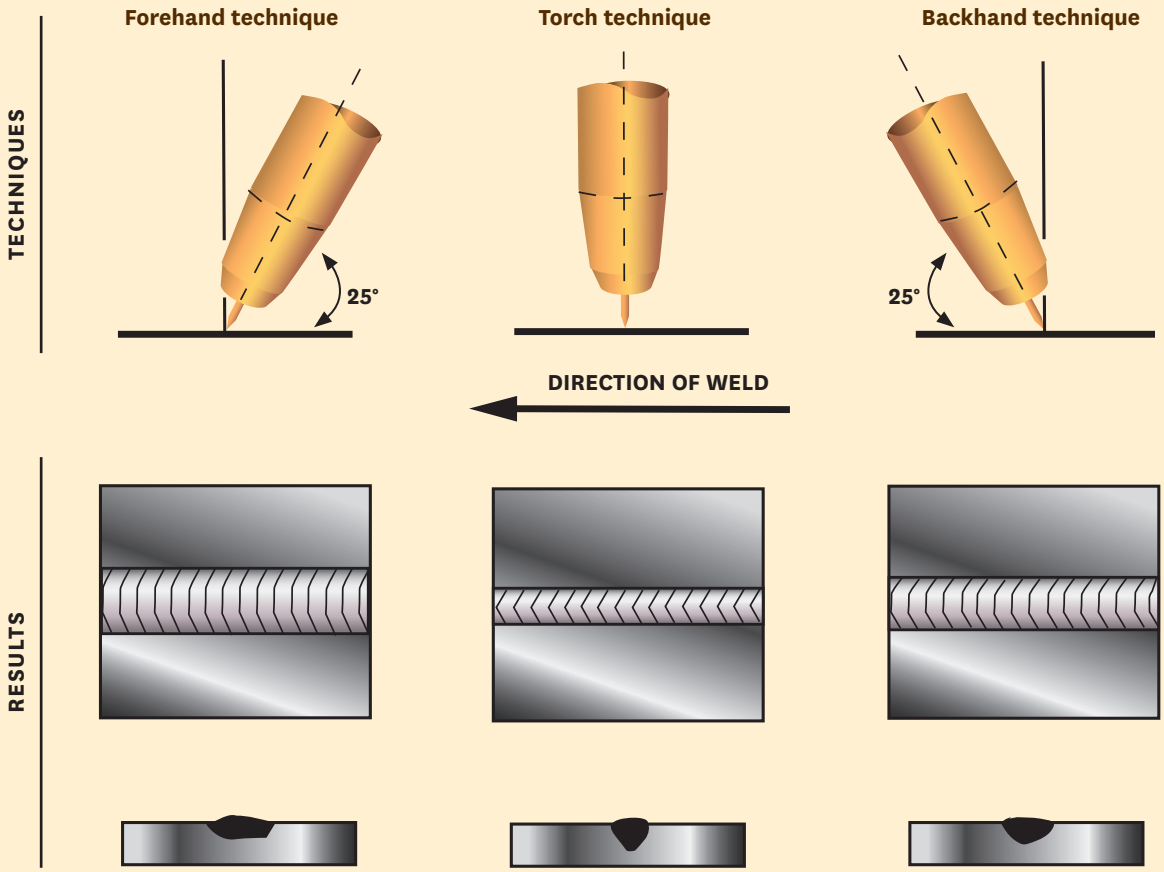
ORIENTATION OF THE ELECTRODE AND HOW IT AFFECTS THE WELD

How the gun is held affects the weld bead. There are three welding positions, or techniques: forehand, torch, and backhand. Each offers different weld characteristics, affecting the bead width and penetration.

FOREHAND TECHNIQUE. The gun is tipped toward the direction of welding and produces a lead angle. Going from perpendicular to a lead angle provides less penetration and a wider, thinner weld. On some materials, particularly aluminum, a lead technique produces a cleaning action just ahead of the weld pool. This promotes wetting — the visible intermelting and fusion of the wire-feed electrode with the base metal — and reduces base metal oxidation.

TORCH TECHNIQUE. The gun is perpendicular to the direction of welding. It has neither a lead nor a drag angle and produces a narrower weld than the forehand or backhand techniques do.

BACKHAND TECHNIQUE. The gun is tipped away from the direction of welding and produces a drag angle. Maximum penetration occurs in the flat welding position with a drag angle of 25 degrees from perpendicular. For all other positions, the backhand technique is used with a drag angle of 5 to 15 degrees.



Each of the three welding positions produces different bead characteristics.

Typical MIG Welding Problems and Solutions

A number of variables go into producing a quality weld, such as equipment adjustments and good technique. Learn to spot defects within your welds and understand how to correct them. This table provides some good starting points for troubleshooting, but it is by no means comprehensive.

Problem	Possible Cause	Remedy
UNDERCUTTING	Travel speed too high	Use slower travel speed
	Welding voltage too high	Reduce voltage
	Excessive current	Reduce wire feed speed
	Insufficient dwell	Increase dwell at puddle edge
	Improper gun angle	Change gun angle so arc force helps in placing metal
POROSITY	Inadequate shielding gas coverage	Adjust gas flow Shield work from drafts Decrease torch to work distance Hold gun at end of weld until metal solidifies
	Gas contamination	Use welding-grade shielding gas
	Electrode contamination	Use clean and dry electrodes
	Workpiece contamination	Remove all dirt, rust, paint, and moisture from work's surface
	Arc voltage too high	Reduce voltage
	Excessive contact tube-to-work distance	Reduce stickout
INCOMPLETE FUSION	Weld zone surfaces not clean	Clean weld surfaces carefully
	Insufficient heat input	Increase wire feed speed and voltage
	Weld puddle too large	Reduce weaving, increase travel speed
	Improper weld technique	When weaving, dwell momentarily at edge of groove
	Improper joint design	Use joint design with suffiently wide angle to provide access to all of groove bottom
	Excessive travel speed	Reduce travel speed

Problem	Possible Cause	Remedy
INCOMPLETE JOINT PENETRATION	Weld zone surfaces not clean ▶	Clean weld surfaces carefully
	Insufficient heat input ▶	Increase wire feed speed and voltage
	Weld puddle too large ▶	Reduce weaving, increase travel speed
	Improper weld technique ▶	When weaving, dwell momentarily at edge of groove
	Improper joint design ▶	Use joint design with sufficiently wide angle to provide access to all of groove bottom
	Excessive travel speed ▶	Reduce travel speed
EXCESSIVE MELT-THROUGH	Excessive heat input ▶	Reduce wire feed speed
	Improper joint penetration ▶	Reduce root opening Reduce root face dimension
WELD METAL CRACKS	Improper joint design ▶	Alter joint angle to provide adequate weld metal to overcome constraint conditions
	Too high a weld depth-to-width ratio ▶	Decrease arc voltage, decrease wire feed speed, or both
	Weld bead too small (particularly in fillet and root beads) ▶	Decrease travel speed
	Hot shortness (result of high working temperatures) ▶	Use electrodes with higher manganese content Increase groove angle to increase filler metal in weld Change filler metal
	High restraint of joint members ▶	Preheat Adjust welding sequence
HEAT AFFECTED ZONE (HAZ) CRACKS	Hardening in the HAZ ▶	Preheat to retard cooling rate
	Residual stresses too high ▶	Use stress-relief heat treatment
	Hydrogen embrittlement ▶	Use clean electrode Use dry shielding gas Hold weld at elevated temperature for several hours to permit diffusion of hydrogen out of weld

Working Tips for MIG Welding

Because the electrode, filler rod, and flux are all contained within the nozzle of the welding gun, the MIG process is much easier to master than other types of welding. It also means you can use two hands to hold the gun steady. You can use either the *forehand technique,* where the gun is pushed in the direction of travel, or the *backhand technique,* where the gun is dragged in the direction of travel; see Orientation of the Electrode and How It Affects the Weld on page 147.

▲ After adjusting the stickout, squeeze the trigger and touch the electrode to the work to start. (Here, the welder used tack welds to keep this T-joint stable.) Try to maintain a contact-tip-to-work distance of ⅜ to ½ inch. Make smaller ovals with the tip as you move forward.

▲ Pulling the gun along the joint gives the welder a clear view of the joint. Hold the gun at about a 35-degree angle for best results.

▲ Notice the consistent ridges and how the bead is even on both sides of the seam.

SETTING THE ARC VOLTAGE

As mentioned earlier, arc length is controlled by the arc voltage setting, and arc voltage depends on the materials being welded, the shielding gas, and the metal transfer mode.

Too short an arc may produce stubbing, where cold wire pushes into the workpiece, upsetting the smooth flow of shielding gas and pumping air into the arc stream, resulting in porosity and cracking from atmospheric nitrogen.

Too long an arc can cause the arc to wander, degrading both penetration and weld bead quality. In general, higher voltages tend to flatten the weld bead and increase the width of the fusion zone. Very high arc voltages can cause porosity, undercut, and spatter.

The best way to set arc voltage is to begin with the recommended voltage given on AWS welding tables or the electrode manufacturer's data sheets. However, this is just a starting point; exact refinement often requires several trial runs.

For short-circuit transfer, set the constant-voltage (CV) power supply at 18 volts, and set your wire feed speed at 210 inches per minute as a beginning setting. Observe what is happening to the weld area:

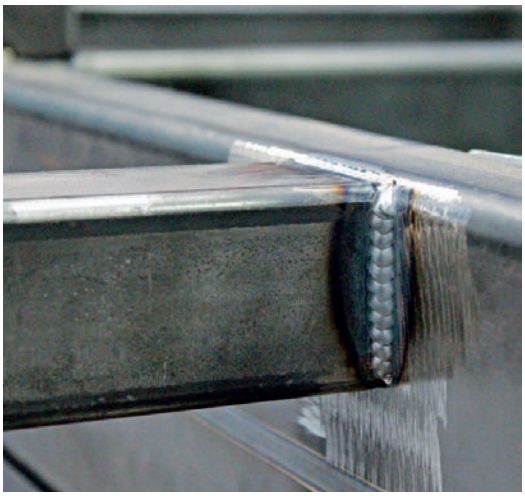
- If the welding wire coming from the contact tip melts but the metal you are welding is not melting, increase the voltage.
- If the welding wire is coming out too fast and pushing into the material (stubbing), increase the voltage setting one notch at a time. Do not increase a full number until the short-circuiting begins and the sound of the welding is similar to the sound of bacon frying.
- If the welding wire forms droplets and splashes into the molten pool, decrease the voltage.

DETERMINING WIRE FEED RATE

On many wire-feed machines, wire feed rate is indicated on the speed control or a digital readout, but the best way to check the speed is to run out electrode (being careful not to permit an arc) for 1 minute, then measure the wire output. Usually, each number on a wire feed speed adjustment scale represents an increment of 70 inches per minute. Typically, both the wire feed rate and the arc voltage need adjustment to produce the optimum weld.

OVERALL BEST PRACTICES

- Keep equipment in good working order.
- Keep bends out of the MIG hose.
- Prepare all metal properly. Finish prep work by wiping down the metal, using acetone. The cleaner the metal, the cleaner the weld.
- Never let the equipment sit outside because the electrode wire can become contaminated.
- Stay relaxed when welding. The more relaxed you are, the better the results. Hold the gun with one hand, and use the other hand to support the gun hand.

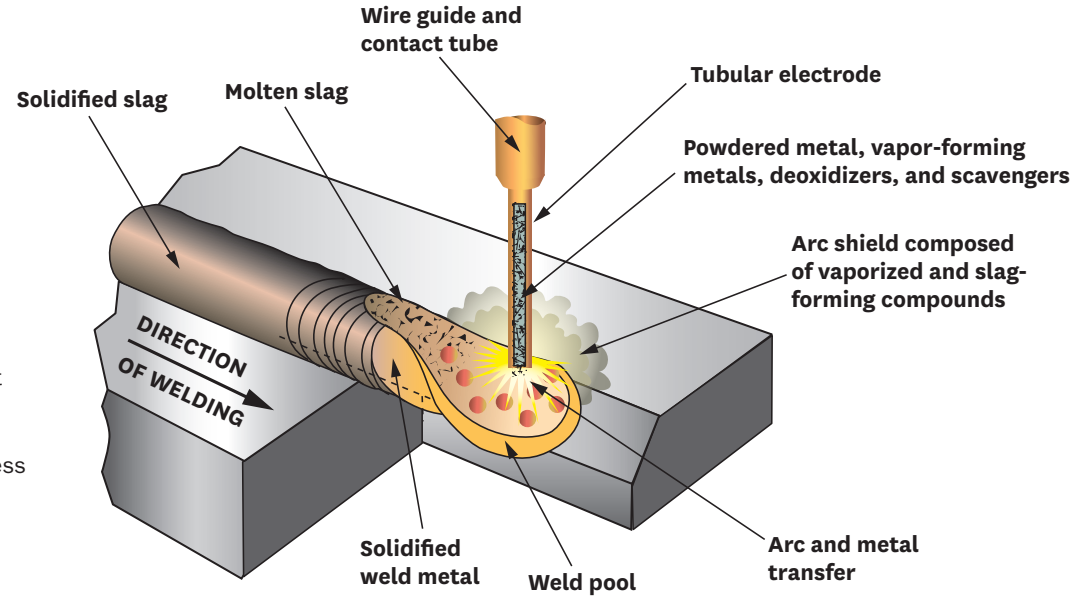


▲ A well-prepared and practiced weld bead looks even, consistent, and clean.

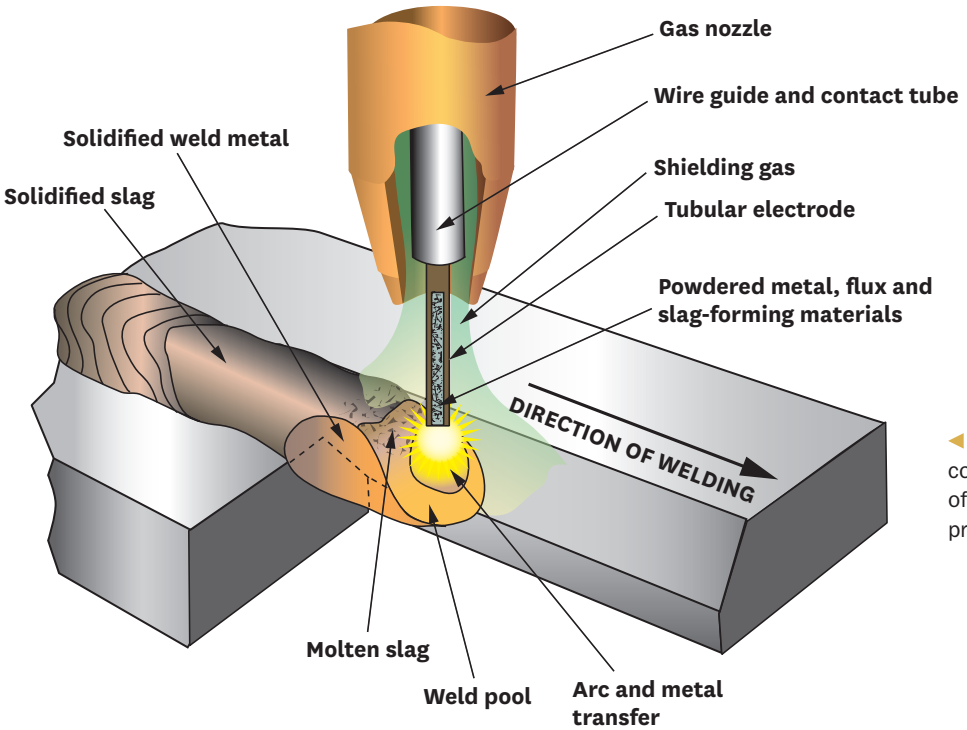
The Flux-Cored Arc Welding (FCAW) Process

The structure and chemical composition of FCAW electrode wire makes the difference between MIG and FCAW. Unlike MIG, the FCAW electrodes consist of a thin-walled metal tube — not a solid wire — filled with powdered flux. The flux provides alloying elements, arc stabilizers, denitriders, deoxidizers, flag formers, and shielding gas–generating chemicals. For many electrodes, the volume and forcefulness of the shielding gas emitted eliminates the need for external shielding gas. Depending on the electrode, both DCEP and DCEN are used; AC is not used.

Metals that can be welded with FCAW include only ferrous metals and nickel-based alloys. This includes all low- and medium-carbon steels, some low-alloy steels, and stainless steels.



▶ A close-up look at the components and elements of the self-shielded FCAW process



◀ An up-close look at the components and elements of the gas-shielded FCAW process

PROS AND CONS OF FCAW

ADVANTAGES

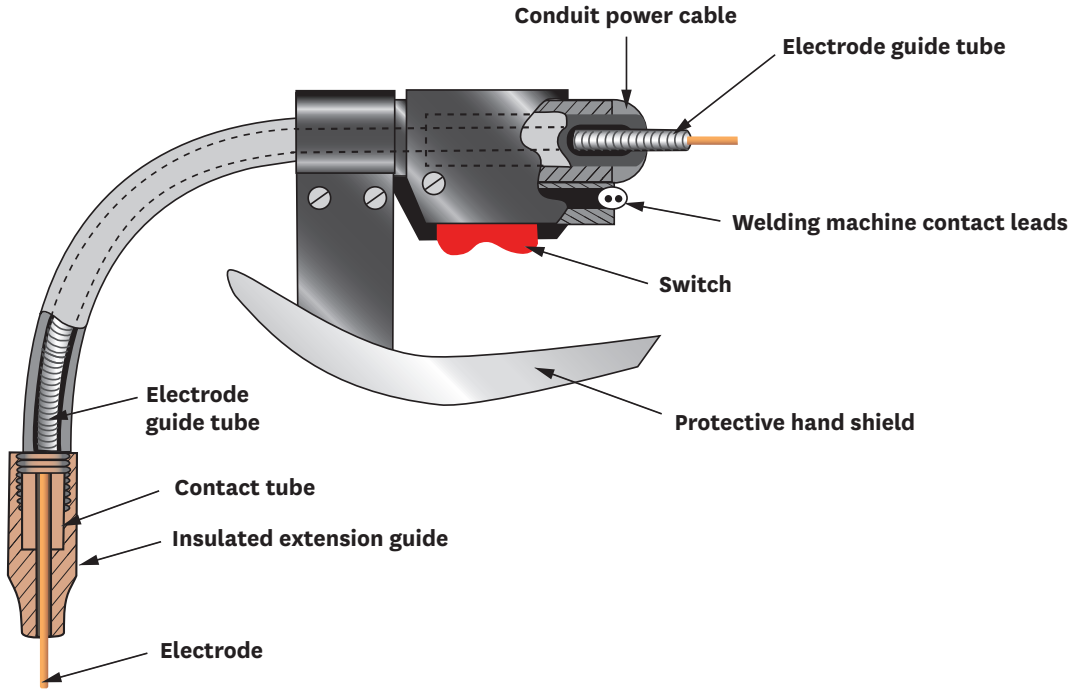
- Because of its excellent penetration, FCAW can use groove angles as narrow as 30 degrees. This can save as much as 50 percent of the filler metal compared to SMAW, which requires larger groove angles. In some cases, FCAW allows you to avoid joint beveling in metal up to ½ inch thick.
- Different thicknesses of material can be welded with the same electrode by adjusting the power supply.
- FCAW is easier to use than SMAW.
- FCAW offers excellent weld pool control.
- FCAW offers better welder visibility of the weld pool than GMAW because the gas diffuser nozzle is not needed and can be removed.
- FCAW is often permitted by codes for critical welds on boilers, pressure vessels, and structural steel.
- FCAW oxidizers and fluxing agents permit excellent-quality welds to be made on metals with some surface oxides and mill scale. Often, metal from flame cutting can be welded without further preparation, a major cost savings.
- High deposition rates of more than 25 pounds per hour are possible, compared with 10 pounds per hour for SMAW with ¼-inch-diameter electrodes.
- Self-shielded FCAW electrodes work better in windy field conditions than gas-shielded GMAW electrodes.
- There is no stub loss, as in SMAW, where losses can total an average of 11 percent of the electrode.
- Materials of unlimited thickness can be joined with multiple passes.
- Welds can be made in all positions.

DISADVANTAGES

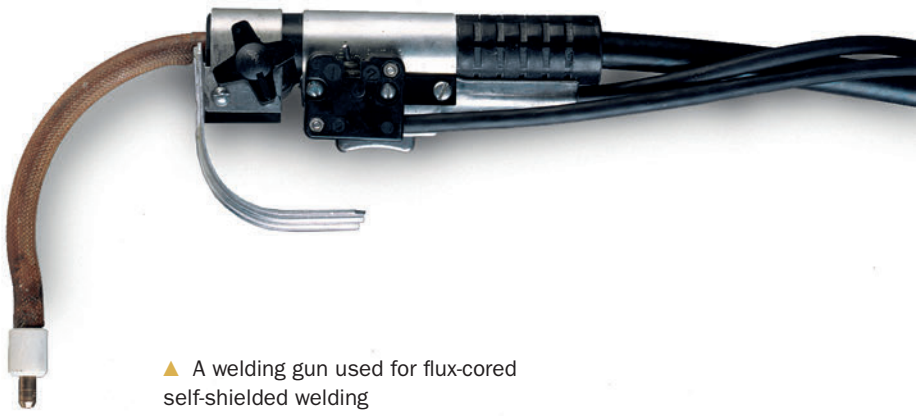
- Slag removal requires an additional step, similar to SMAW.
- FCAW generates large volumes of fumes and smoke, requiring additional ventilation indoors during the process.
- The wire feeder and welder must be close to the point of welding, unlike with SMAW, in which the electrode extends up to one foot from the electrode holder.

Required Equipment for an FCAW Welding Outfit

- FCAW is done with a MIG welder.
- Depending on the welding electrode wire, external gas shielding from a cylinder/flow regulator/flow meter may or may not be needed. Using an external shielding gas when the electrode is designed to work without one can produce a defective weld, so be sure to consult the manufacturer's data sheets.
- Because flux-cored wire is softer than MIG wire, the wire-feed roller may need to be changed and the wire tension will need adjusting to accommodate the flux-cored wire.
- Because very high welding currents are used (they can exceed 250 amperes), many FCAW guns have a sheet metal heat shield to protect the operator's hands from the intense heat of the weld. Although most FCAW guns are air-cooled, some are water-cooled to operate on a 100 percent duty cycle.



▲ FCAW gun with metal heat shield



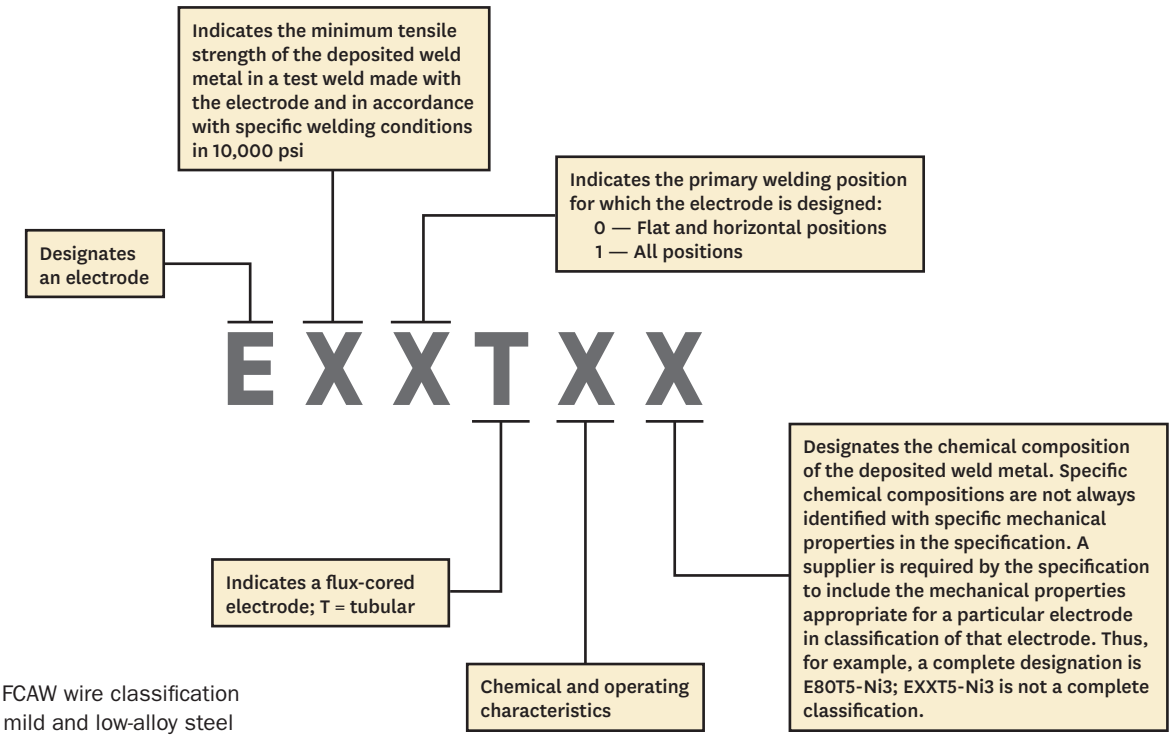
▲ A welding gun used for flux-cored self-shielded welding

Setting Up FCAW Equipment

Flux-cored welding is generally done with a MIG welder and has the same set up. Since the flux-cored electrode is a hollow tube filled with flux, it is softer than MIG welding wire and may require a special knurled drive roll with a U-groove in it. The drive roll tension will have to be decreased as to not crush and flatten the electrode. If a shielding gas is needed, it is likely to be carbon dioxide, which comes in a common mixture of 75 percent argon, 25 percent carbon dioxide, the same shielding gas mixture used for most MIG welding. It does generate quite a bit of smoke and fumes, so proper ventilation and protection is needed. Use the same lens shade as you would for MIG welding.

HOW TO SELECT FCAW ELECTRODES

The type of flux-cored welding wire used depends on a number of factors, including welding position, type of base metal, type of joint, the necessary mechanical properties of the weld, and the environment in which the welding takes place. Some electrodes are more suited for overhead and verticle welds, while others are useful in achieving a quality weld on base metal with rust, scale, or other surface contaminents. Use the chart below and product data information in order to find the electrode you need.


Indicates the minimum tensile strength of the deposited weld metal in a test weld made with the electrode and in accordance with specific welding conditions in 10,000 psi
Indicates the primary welding position for which the electrode is designed:
0 — Flat and horizontal positions
1 — All positions
Designates an electrode
E X X T X X
Indicates a flux-cored electrode; T = tubular
Chemical and operating characteristics
Designates the chemical composition of the deposited weld metal. Specific chemical compositions are not always identified with specific mechanical properties in the specification. A supplier is required by the specification to include the mechanical properties appropriate for a particular electrode in classification of that electrode. Thus, for example, a complete designation is E80T5-Ni3; EXXT5-Ni3 is not a complete classification.

▶ FCAW wire classification for mild and low-alloy steel

Typical FCAW Problems and Solutions

Problem	Possible Cause	Corrective Action
Porosity	• Low gas flow	• Increase gas flow setting Clean spatter-clogged nozzle
	• High gas flow	• Decrease flow to eliminate turbulence
	• Excessive wind drafts	• Shield weld zone from wind or draft
	• Contaminated gas	• Check gas sources Check for leak in hoses and fittings
	• Contaminated base filler	• Clean weld joint faces
	• Contaminated filler wire	• Remove drawing compound on wire Clean oil from rollers Avoid filler wire Rebrake filler wire
	• Insufficient flux in core	• Change electrode
	• Excessive voltage	• Reset voltage
	• Excessive electrode stickout	• Reset stickout and current
	• Insufficient electrode stickout	• Reset stickout and current
	• Excessive travel speed	• Adjust speed
	• Insufficient electrode stickout (self-shielded electrodes only)	• Reset stickout and balance current
Incomplete fusion or penetration	• Improper manipulation	• Direct electrode to joint root
	• Improper parameters	• Increase current Reduce travel speed Decrease stickout Reduce wire size Increase travel speed (self-shielded electrodes)
	• Improper joint design	• Increase root opening Reduce root face

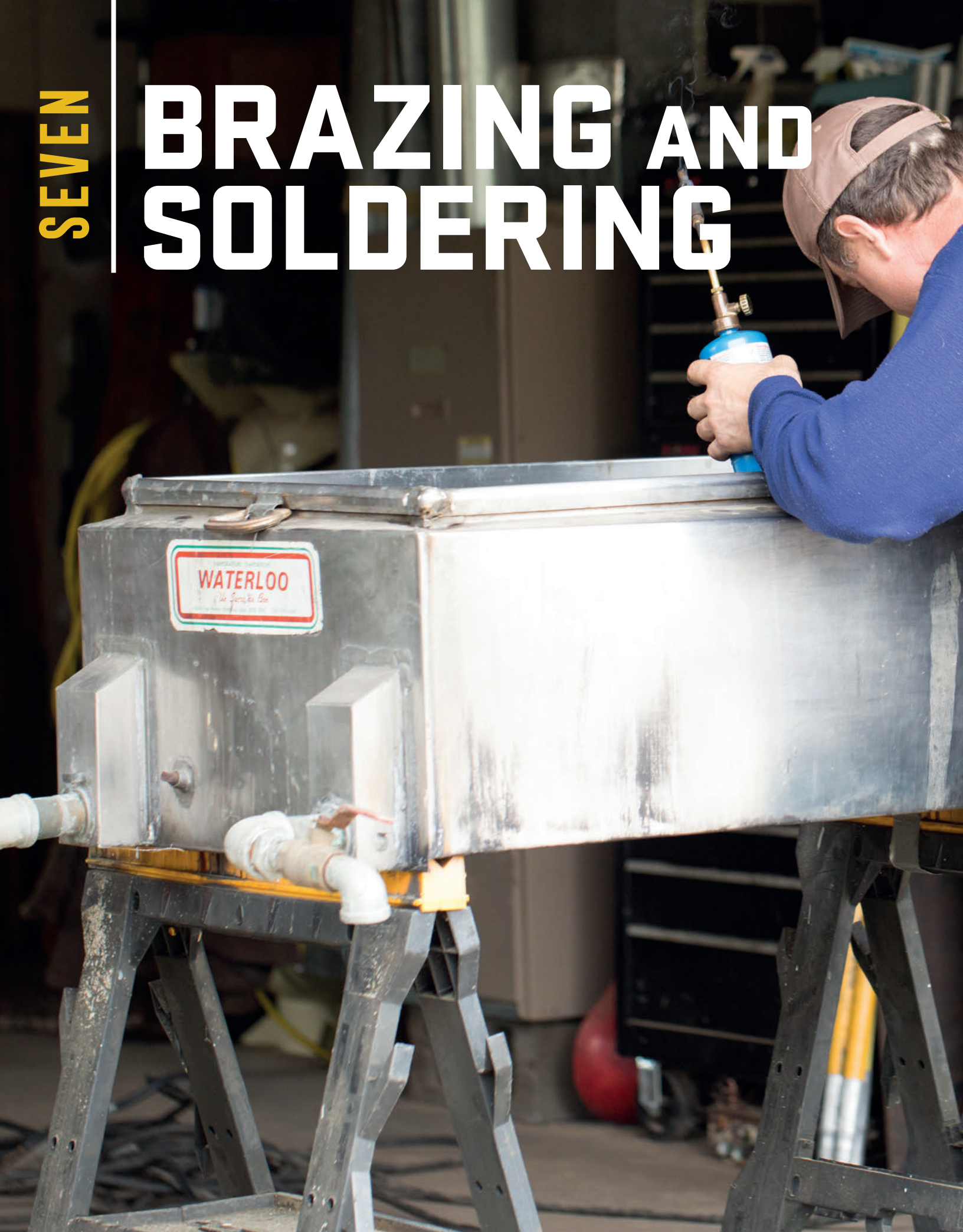
Problem	Possible Cause	Corrective Action
Cracking	• Improper manipulation	• Reduce restraint Preheat Use more ductile metal Employ peening
	• Improper electrode, insufficient deoxidizers, or inconsistent flux fill in core	• Check formulation of flux
Electrode feeding	• Excessive contact tip wear	• Reduce drive roll pressure
	• Melted or stuck contact tip	• Reduce voltage
	• Dirty wire conduit in cable	• Change conduit liner Clean out the liner with compressed air

Shielding and Polarity Requirements for Mild Steel FCAW Electrodes

AWS Classification	Shielding Gas	Welding Position	Current & Polarity	Minimum Tensile Strength (PSI)
E70T-1C	CO_2	Flat/Horizontal	DCEP	70,000
E71T-1C/M	CO_2 or Ar/CO_2	All	DCEP	70,000
E70T-2C/M	CO_2 or Ar/CO_2	Flat/Horizontal	DCEP	70,000
E70T-3	None	Flat/Horizontal	DCEP	70,000
E70T-4	None	Flat/Horizontal	DCEP	70,000
E70T-5C/M	CO_2 or Ar/CO_2	Flat/Horizontal	DCEP	70,000
E70T-7	None	Flat/Horizontal	DCEN	70,000
E71T-8	None	All	DCEN	70,000
E71T-9C/M	CO_2 or Ar/CO_2	All	DCEP	70,000
E71T-11	None	All	DCEN	70,000
E71T-12C/M	CO_2 or Ar/CO_2	All	DCEP	70,000

SEVEN

BRAZING AND SOLDERING



Brazing and soldering

are two processes complementary to welding and are just as essential for home repairs and projects in the garage, shop, and on the farm or in the field. Although soldering and brazing do not make joints as strong as welded connections, they have their own applications that are commonly used in a wide range of fabrication and fixes, including electrical wire connections and household plumbing. In this chapter, we'll discuss the theory, safety issues, materials, fluxes, common processes of brazing and soldering, and some advantages they have over welding. Look to the end of this chapter to learn how to solder copper pipe for plumbing; it's something every welder should know how to do.

The Difference Between Brazing and Soldering

Brazing joins materials that have been heated to the brazing temperature, followed by adding a brazing filler metal that has a melting point above 840ºF (450ºC). This temperature is below the melting point of the base metals being joined so that the base metals remain solid. The nonferrous filler metal is drawn into and fills the closely fitted mating, or *faying*, surfaces of the joint by capillary attraction. The filler material, usually aided by fluxes, is *wetted* — it is liquefied and spreads and adheres in a thin, continuous layer onto the solid base metals. The flux allows the filler material to flow more readily through and between the two mating surfaces. When the filler metal cools and solidifies, the base materials are joined.

The above description also applies to soldering, except that brazing takes place *above* 840ºF (450ºC) and soldering *below* 840ºF (450ºC). Otherwise, the processes are quite similar. They both depend on capillary attraction to draw filler metal or solder into the joint. In general, brazed joints are stronger than soldered joints because of the strength of the alloys used in the filler material.

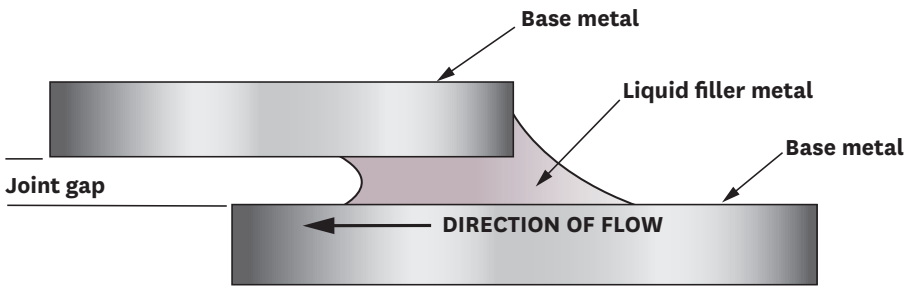
BRAZE WELDING

Do not to confuse brazing with *braze welding*. Brazing depends on capillary attraction to draw the filler metal into the mating joint, while in braze welding the filler metal is deposited in grooves or fillets at the points where they are needed for joint strength. Capillary attraction is not a factor in distributing the filler metal because the joints are open to the welder. Braze welding is *not* a brazing process, but rather welding with brazing filler metal. Braze welding is frequently used to repair cracked or broken cast iron (which is brittle and difficult to weld properly). Joint design is similar to that for oxyacetylene welding: V-groove butt joints, lap joints, T-joints, fillets, and plug joints. See Braze Welding on page 178 for more information.

SUITABLE METALS FOR BRAZING AND SOLDERING

Most common metals can be brazed or soldered, including:

- **Aluminum**
- **Bronze**
- **Brass**
- **Cast iron**
- **Copper**
- **Stainless steel**
- **Steel**
- **Titanium**
- **Tool steels (some)**
- **Tungsten carbide (tool bits)**



▲ Capillary forces draw molten filler metal into a brazed joint.

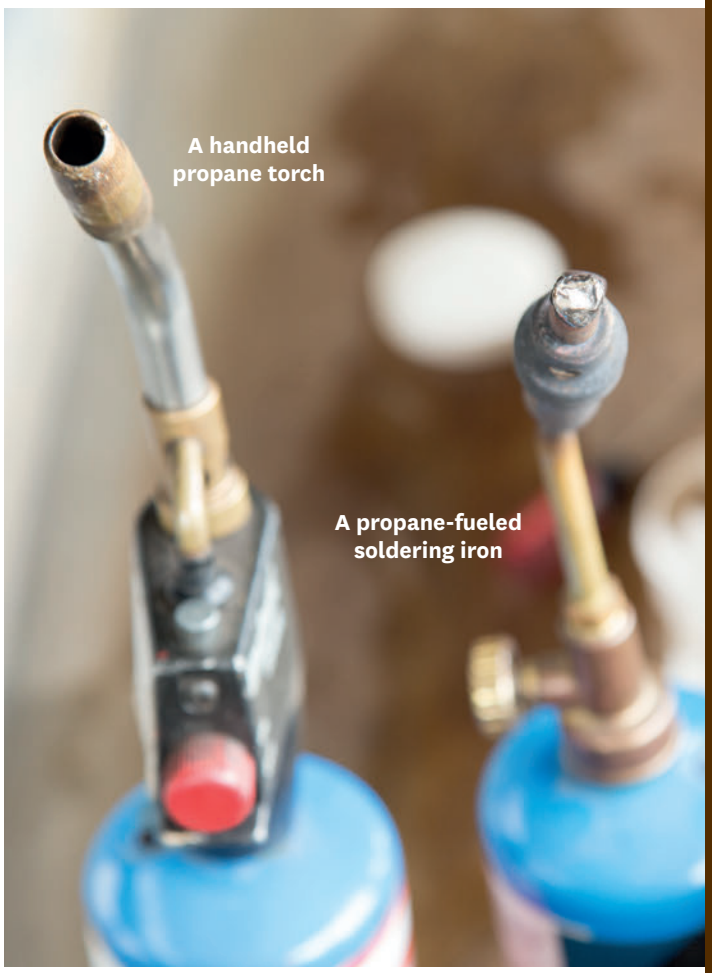
PROS AND CONS OF BRAZING AND SOLDERING

ADVANTAGES

- Ability to join dissimilar metals: Steel is easily joined to copper, cast iron to stainless steel, and brass to aluminum; many combinations of metals are readily joined
- Ability to join nonmetals to metals: Ceramics are easily joined to metals, or to each other
- Ability to join parts of widely different thicknesses: Either thin-to-thin or thin-to-thick parts may be joined without burn-through or overheating
- Excellent stress distribution: Many of the distortion problems of fusion welding are eliminated because of the lower process temperature and the even distribution of heat with more gradual temperature changes, as well as the ductility (ability to be shaped) of the braze material
- Low temperature process: The components being joined are less likely to be damaged because the base metals are not subjected to melting temperatures
- Joins precision parts well: With proper jigs and fixtures, parts, such as carbide tooling or tips, can be very accurately positioned.
- Parts can be temporarily joined, subjected to other manufacturing processes, and then separated without damage
- Mistakes are readily fixed: A misaligned part can be repositioned without damage
- Ability to make leakproof and vacuum-tight joints
- Joints require little or no finishing: With proper process design, the brazed or soldered joint can be nearly invisible

DISADVANTAGES

- While brazing processes can produce high-strength joints, they are rarely as strong as a fusion-welded joint
- The brazed parts and the filler metal are not always color-matched



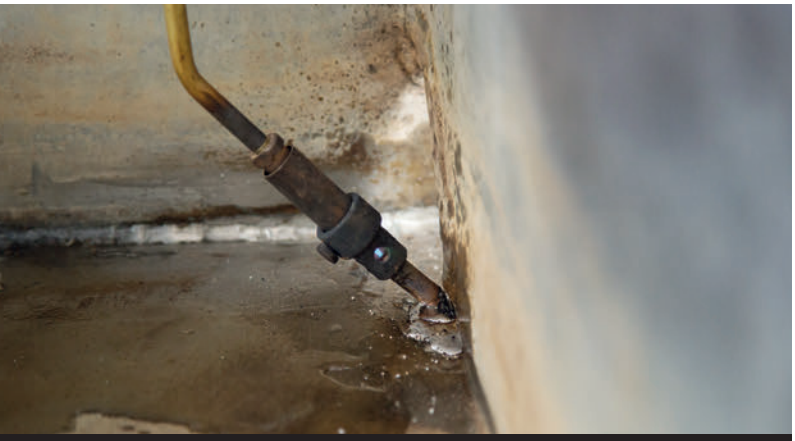
Types of Brazing and Soldering

As you become more experienced working with metal you'll discover that many techniques are simply variations of other techniques. Such is the case with torch brazing and torch soldering, where the methods are essentially the same, except that soldering takes place at a lower temperature.

TORCH BRAZING

With torch brazing, the heating is done with one or more gas torches. Depending on the size of the parts and the melting point of the filler metal, a variety of torch fuels (acetylene, propane, methylacetylene-propadiene stabilized, or natural gas) can be burned in oxygen, compressed air, or atmospheric air. A neutral or oxidizing flame usually produces excellent results.

Flux is required with most braze filler metals and can usually be applied to the joint before brazing begins. The filler metal can be prefed into the joint. Manual torch brazing is successfully used on assemblies involving components of unequal mass. It is frequently used in the repair of castings in the field and is often automated for high-production of small and medium-size parts. It is a versatile process and probably the most popular brazing technique.



A propane soldering iron melts the filler material into the joint.

TORCH SOLDERING

Torch soldering is very much like torch brazing but at a lower temperature. The heat is usually supplied by propane, methylacetylene-propadiene gas, or natural gas.

The joint is cleaned to shiny metal with emery cloth, wire brushes, steel wool, or commercial abrasive pads. The flux (used for wetting the joining surfaces) is usually applied in liquid or paste form, or it may be alloyed inside the solder wire.

While widely used in manufacturing and maintenance, torch soldering is also used in plumbing to join copper tubing for potable water. See page 170 for a detailed procedure for soldering of copper tubing.

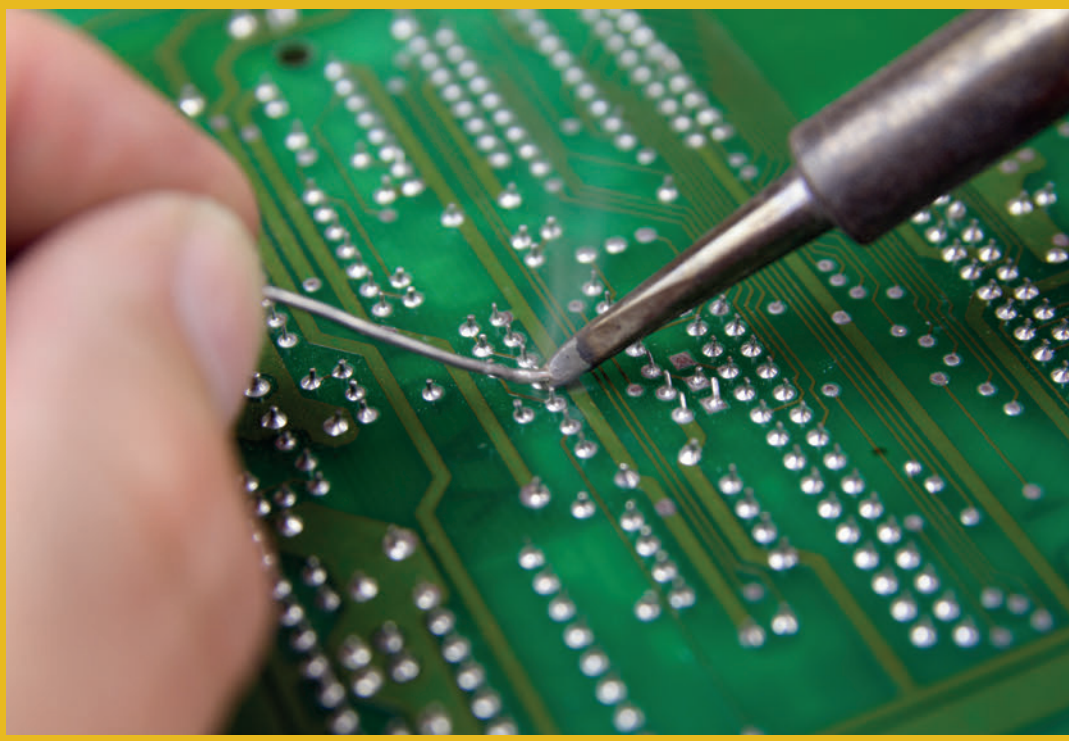
IRON SOLDERING

A modern soldering iron is a simple tool consisting of a copper tip attached to a heat-resistant handle. The tip is heated with electricity and transfers the heat directly to the part(s) to be soldered. When the joint is raised to soldering temperature, solder is applied to the joint itself and wets the entire joint.

The benefit of a soldering iron is that heat is applied only to a specific area, therefore limiting distortion or excessive heating of the surrounding work. This is particularly helpful with thin sheet metals, such as when soldering a maple syrup evaporating pan. Flux-cored solder is used for electronic work. This solder has been formed concentrically around a core of one or more strands of flux. In sheet metal and other nonelectrical work, the flux may also be in the solder core or applied as a paste or a liquid.

Electric soldering irons range in capability from just a few watts (for electronic work) to 1,250 watts (for roofing and heavy sheet metal work). Many irons for electronic work have temperature-controlled tips to prevent damage to the sensitive components.

▲ Propane is a common heat source for soldering.



► An electric soldering iron is used to make repairs to a circuit board.

Common Joint Designs

Well-designed braze joints start with fundamental butt and lap joints. The illustration below shows both a lap joint and a square-edged butt joint. Good joint design ensures a reliable, repeatable production brazing process that will provide a strong joint.

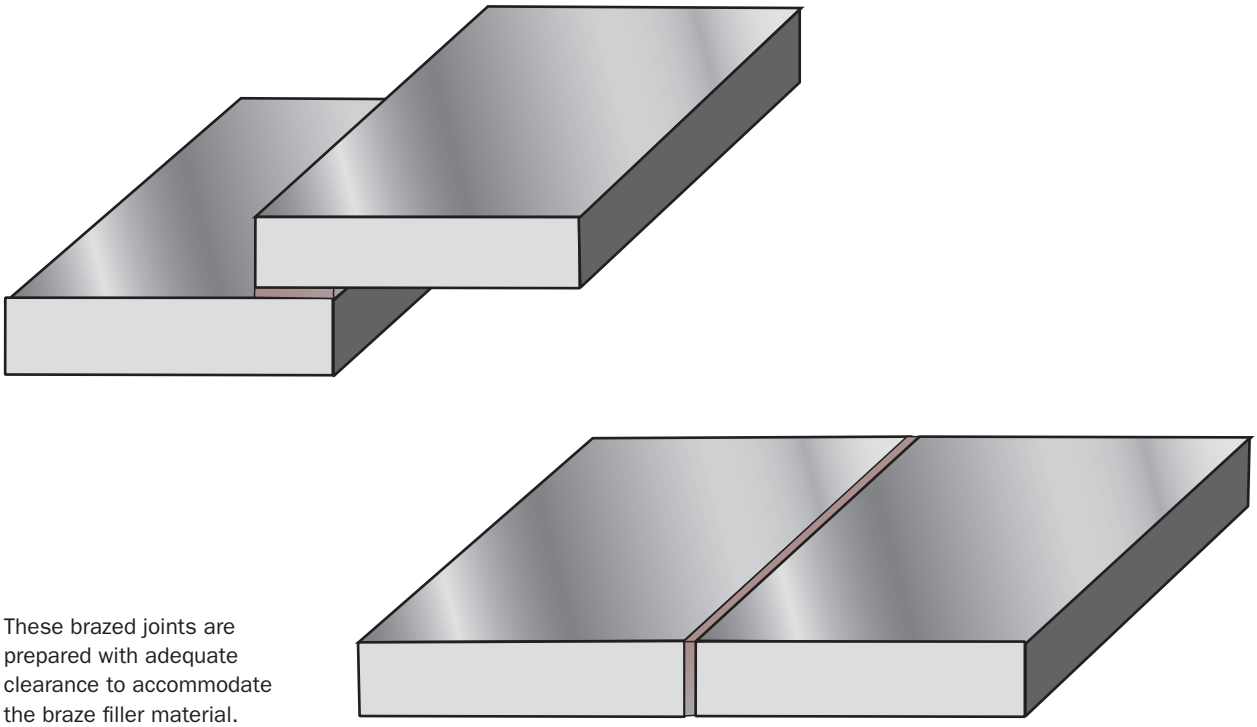
Joint clearances range from 0.002 to 0.010 inch. Assuming that the joint clearance is adequate to admit braze filler material, the lower the joint clearance, the stronger the joint. Too much clearance reduces joint strength; too little permits voids in the joint.

GOOD JOINTS

Several factors influence good joint design. They include:

- **BASE METAL SELECTION.** Differences in base metal thermal expansion coefficients may lead to poor joint fit at brazing temperature, resulting in too much or too little clearance.
- **EFFECT OF FLUX ON CLEARANCE.** Flux must enter the joint *ahead* of the braze filler metal and then be displaced by it, but when joint clearance is too small, the flux may be held in the joint by capillary forces. This prevents proper braze filler entry and creates voids.
- **EFFECT OF JOINT LENGTH AND GEOMETRY ON CLEARANCE.** It's important to consider the amount of stress the joint is likely to receive.

LAP AND BUTT JOINTS



These brazed joints are prepared with adequate clearance to accommodate the braze filler material.

JOINT PREPARATION

Joint preparation involves removing all dirt, paint, and grease from the work so the flux and braze filler metal can readily and completely wet the base metal surface. The objective is getting down to fresh, bare metal. After preparing the joint, complete the soldering immediately, before the base metals have a chance to reoxidize.

There are two classes of cleaning: chemical and mechanical. Chemical is typically used in production applications. Mechanical cleaning, especially with emery cloth, steel wool, or commercial abrasive pads, is effective for most nonproduction work. Many of the same processes used in brazing are also used for soldering. Some common mechanical methods include:

- Grinding
- Filing
- Machining
- Blasting
- Wire brushing
- Sanding

Wire brushes must be free of contaminating materials and selected so none of the wire wheel material is transferred to the part being cleaned. A stainless steel wire brush is a good choice for most materials.

Blasting media must be chosen so it does not embed in the base metal and is easily removed after blasting. Blasting media like alumina, zirconia, and silicon-carbide tend to embed in the base metal and therefore should be avoided.

Before soldering, the joint must be cleaned with a wire brush.

The Purpose of Brazing and Soldering Fluxes

Fluxes further clean the base metal surface after the initial chemical or mechanical cleaning and prevent the base metal from oxidizing while heating, until the brazing material or solder reaches the joint surfaces. They also promote the wetting of the joint material by the braze filler material or solder by lowering surface tension and aiding capillary attraction. Since the flux has a *lower* attraction to the base metal's atoms than the filler or solder, when the filler metal or solder melts, it slides *under* the flux and adheres to the clean, unoxidized base metal surface ready to receive it. Fluxes will not remove oil, dirt, paint, or heavy oxides, so the joint surface must already be clean for them to work.

BRAZING FLUXES

Brazing fluxes usually contain some combination of: fluorides, chlorides, borax, borates, fluoroborates, alkalis, wetting agents, and water. A traditional and still commonly used flux is 75 percent borax and 25 percent boric acid (borax plus water) mixed into a paste.

Representative Brazing Flux Categories

Base Metals Being Brazed	Filler Metal Type	AWS Flux Class	Typical Flux Ingredients	Activity Temperature Range	
				°F	°C
All brazeable aluminum alloys	BAlSi	FB1-A (Powder)	Fluorides Chlorides	1080–1140	582–615
All brazeable ferrous and nonferrous metals except those with Al or Mg as a constituent; also for brazing carbides	BAg and CuP	FB3-A (Paste)	Borates Fluorides	1050–1600	565–870
	BAg, BCuP, and BCuZn	RB3-K (Liquid)	Borates	1400–2200	760–1205
Brazeable base metals containing up to 9% Al (Al-brass, Al-bronze, Monel K500)	BAg and BCuP	FB4-A (Paste)	Chlorides Fluorides Borates	1100–1600	595–870

NOTE: The letter *B* in filler metal indicates brazing usage, not the chemical element boron.

Al = Aluminum Si = Silicon Ag = Silver Cu = Copper Mg = Magnesium P = Phosphorous Zn = Zinc

The *AWS Brazing Manual* provides specifications for brazing and brazing fluxes. This specification has 15 classifications of fluxes. Many manufacturers supply proprietary flux mixtures meeting these specifications.

SOLDERING FLUXES

The main types of soldering fluxes are:

ORGANIC FLUXES. These consist of organic acids and bases. After soldering they can be removed with water and are widely used in electronics.

INORGANIC FLUXES. These contain no carbon compounds, so they do not char or burn easily and are used in torch, oven, resistance, and induction soldering. They are not used for soldering electrical joints.

ROSIN-BASED FLUXES. These are easily cleaned from parts after soldering. They are usually noncorrosive; available as powders, pastes, liquids, and as a core within soldering wire. They are used in electrical and electronics applications.

Application
For torch or furnace brazing
General-purpose flux for most ferrous and nonferrous alloys; notable exception is aluminum bronze
Exclusively used in torch brazing by passing fuel gas through a container of flux; flux is applied by the flame
General-purpose flux for many alloys that form refractory oxides

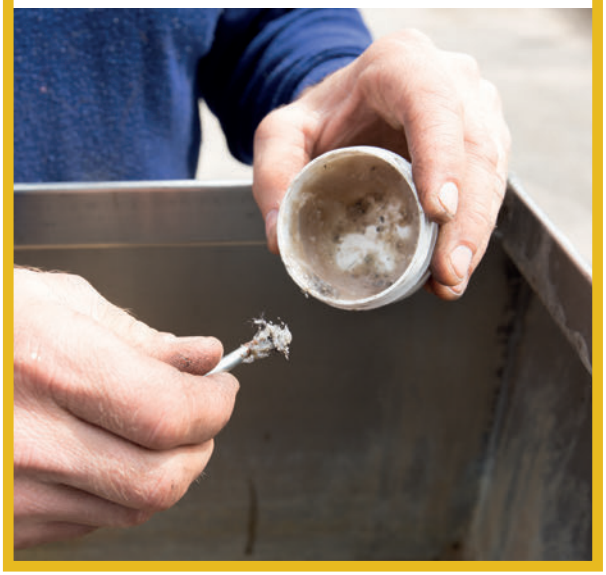
FLUX APPLICATION

FOR BRAZING:

- **Apply flux by spraying, brushing, or dipping.**
- **Heat the brazing rod using a torch, and dip the rod into powder flux.**
- **Some brazing (and braze welding) rods come from the factory with flux already applied to the outside.**

FOR SOLDERING:

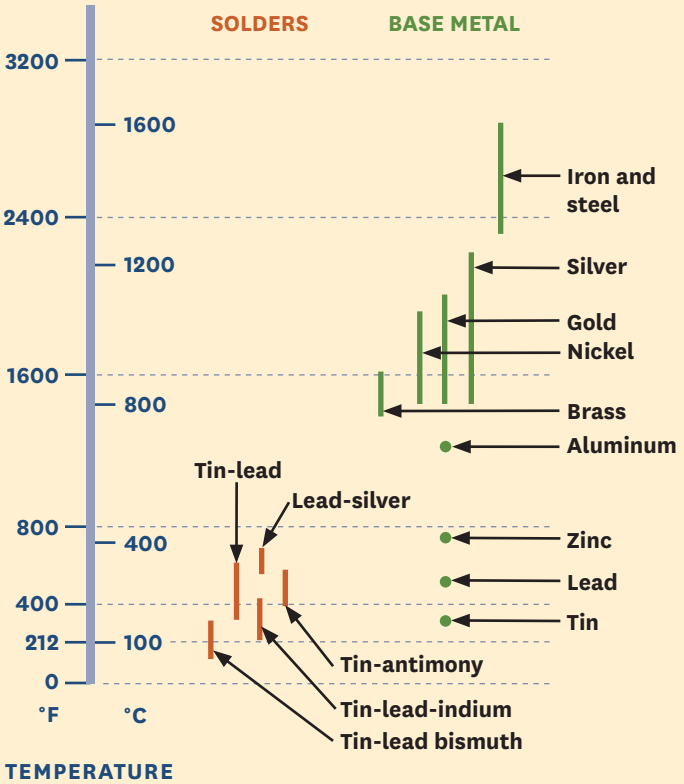
- **Soldering fluxes are brushed, rolled, or sprayed. Many solders have flux cores, so no separate fluxing step is needed.**



An artist uses filler material while working on a sculpture.

Melting Points

Melting points of braze filler metals and solders fall well below most base metals.



Properties of Brazing Filler Materials and Soldering Alloys

Brazing filler materials must have the ability to make joints with mechanical and chemical properties suitable for the application. They must have a melting point below that of the base metals being joined and the right flow properties to wet the base metals and fill joints by capillary attraction. A filler material also must have a composition that will prevent it from separating into its components during brazing.

COMMON BRAZING FILLERS

Filler materials covered by AWS specifications are grouped as:

- Aluminum-silicon
- Copper
- Copper-phosphorus
- Copper-zinc
- Heat-resisting material
- Magnesium
- Nickel-gold
- Silver

COMMON SOLDERS

Tin-lead alloys are the most common solders. It is customary to indicate the tin percentage first, followed by the lead content. The same identification is used with other two-metal alloys. A 40/60 tin-lead solder is 40 percent tin and 60 percent lead.

Tin-lead solders 35/65, 40/60T, and 50/50 are popular because of their low *liquidus* temperatures, which is the lowest temperature at which a metal is completely liquid. Tin-lead solders 60/40 and the 63/37 eutectic are used when low processing temperatures are needed. Tin-silver, tin-copper-silver, and tin-antimony alloys are used where lead must be eliminated for health reasons. such as in stainless steel fabrication for kitchens, food processing equipment, and copper potable water systems. Never use lead-containing solder on potable water systems.

Wear a respirator, especially if you're not working in a well-ventilated area.

Steps to Ensure Safe Brazing and Soldering

Base metals and filler metals may contain toxic materials, such as antimony, arsenic, barium, beryllium, cadmium, chromium, cobalt, mercury, nickel, selenium, silver, vanadium, or zinc. These are vaporized during brazing or soldering and can cause skin, eye, breathing, or serious nervous system problems. Some of these toxic materials, such as lead, are cumulative and can be absorbed through the skin. The following precautions are essential:

- Keep your head out of the brazing or soldering plume.
- Perform brazing or soldering in a well-ventilated area.
- Use respiratory equipment if normal ventilating equipment is not available.

Many brazing and soldering fluxes contain fluorides. Others contain acids and aluminum salts. The following precautions apply:

- Avoid direct contact with skin.
- Do not eat or keep food near these materials.
- Do not smoke around these materials. Keep fire extinguishers close at hand.
- Ensure MSDSs (material safety data sheets) are affixed to containers of these materials and major equipment using them so they are visible to you and others.
- Protect skin from sparks and hot metal by wearing the appropriate gloves and nonflammable clothing.
- Provide adequate ventilation when using cleaning solvents to prepare joints; chlorinated hydrocarbons are toxic and may create phosgene gas when heated.

EYE PROTECTION

For soldering, wear safety glasses or face shields to protect the eyes from external injuries caused by sparks, flying metal, or solder splashes.

For brazing, using a number 5 tinted lens will protect against internal (retinal) eye damage caused by viewing the radiation coming off of hot metal. Some brazing requires darker lens shades of up to number 8.

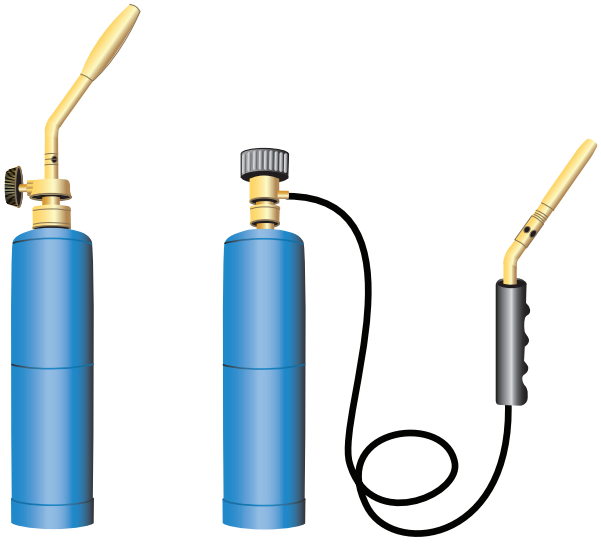
How to Solder Copper Tubing

Brazing and soldering have many uses, but the most common is using solder to join sections of copper tubing in home water systems. By U.S. federal law, only lead-free solders, pipe, and fittings may be sold or used in drinking water systems. These solders are commonly 95-5 tin-antimony but may include a variety of other alloys of about 95 percent tin combined with copper, nickel, silver, antimony, bismuth, or other alloying elements. These lead-free solders can cost four to eight times as much as the tin-lead alloys they replace.

Copper tubing is available in *drawn* or *annealed* condition. Drawn copper tubing cannot be bent (unless it has been annealed) without having its sidewalls collapse. It comes only in straight lengths of 12, 18, and 20 feet and is ideal for straight runs where appearance is important. Annealed tubing comes in both coils and straight lengths and can be easily bent without tools (in smaller-diameter sizes) without wall collapse. Because it can be formed to bend or fit around obstacles along its path, many fittings (and copper soldering joints) can be eliminated by using a *single* piece of annealed tubing. There are three common wall thicknesses: Type K (heaviest), Type L (standard), and Type M (lightest). All three are used in domestic water service and distribution. Budget, preference, and local codes govern this choice.

TORCH SELECTION

Air-acetylene, propane, and MAPP gas torches all work well for soldering copper tubing. BernzOmatic torches burn either propane or MAPP gas. Changing the gas orifice is all that is required to switch between fuels. MAPP gas is more expensive than propane and has a hotter flame, so it can heat the pipe and fitting faster and handle larger-diameter tubing. The version with a separate regulator, 48-inch (1.2 m) hose, and hand piece is especially convenient. It can apply heat in tight quarters and does not stall out when inverted, as the single-piece torch does.



Two basic torches are the torch-on-cylinder model (left) and the hose-based model (right).

DRAINAGE SYSTEMS

Lead-containing solders may be used in drainage systems. The most common are 50-50 tin-lead and 60-40 tin-lead alloys, because they cost less than lead-free solder alloys. However, with the exception of the 95-5 tin-antimony solder alloy, the lead-free solders have a wider pasty temperature range than the traditional 50-50 and 60-40 tin-lead solders. They also are easier to handle and are gaining popularity even where a lead-free solder is not required.

PREPARING COPPER TUBING

1 Measure the tubing length for cutting. The tubing must be long enough to reach to the cup (bottom) of its fitting, but not so long as to cause stress in the completed piping.

2 Cut the tubing, preferably with a disc-type tubing cutter to ensure square ends. A hacksaw, an abrasive wheel, or a portable or stationary band saw may also be used.

3 Remove burrs from inside the tubing ends with a round file, half-round file, or reamer. Many disc-type tubing cutters include a triangular blade for inside reaming. Remove outside burrs with a file because these burrs prevent proper seating of the tubing into the fitting cup. A properly reamed piece of tube provides an undisturbed surface through the entire fitting for smooth, laminar flow, and minimum pressure drop of the liquid.

4 Use emery cloth, nylon abrasive pads (such as 3M Scotch-Brite), or male and female stainless steel brushes sized to the tubing to remove the dirt and oxide from the end of the tubing and the inside mating surfaces of the fitting. An electric drill can drive the male stainless steel internal brush and save a lot of elbow grease on a large job. The goal is to get down to fresh, shiny metal. Clean the outside of the tubing from the end of the tubing to about ⅜ inch beyond where the tubing enters the fitting.

NOTE: The capillary space between the tubing and its fitting is about 0.004 inch. Filler metal fills this gap. Removing too much metal from either the tubing or the fitting will prevent proper flow of solder around the tubing by capillary forces, weakening the joint. Do not touch the cleaned area with bare hands or oily gloves. Skin oils, lubricating oils, and grease impair the adherence of filler metal.

Clean the end of the tubing to remove dirt and oxides. The goal is to get down to shiny metal.

5 Select the flux to match the solder; a mismatch may cause problems. Use a flux meeting ASTM B 813 requirements.

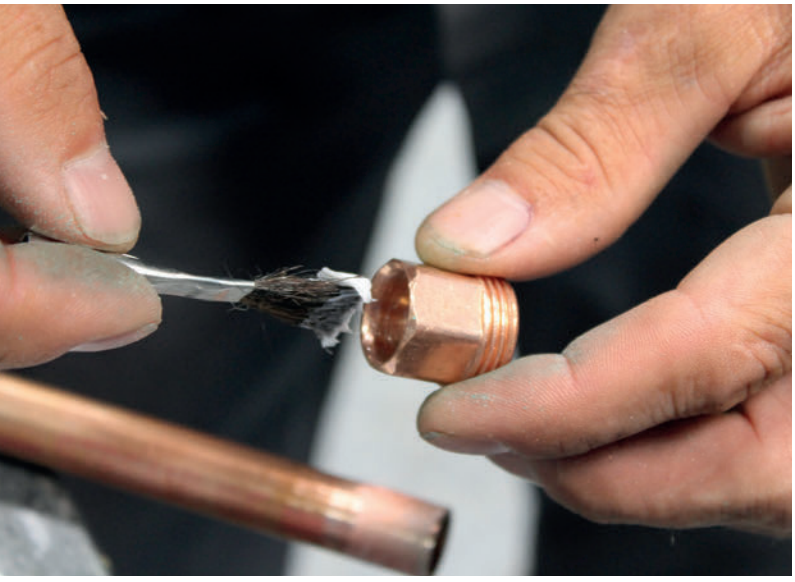
6 Use a brush to apply a thin coating of flux to the ends of the tubing and the fitting's interior mating surfaces. A disposable acid brush works well.

Coat the end of the tubing with flux that is recommended for the solder you are using.

7 Insert the tubing end into the fitting with a twisting motion. Make sure the tubing is properly seated in the fitting cup. If there are multiple lengths of tubing going into one fitting, insert all the tubing into the fitting so they can all be soldered in one operation. This saves work time and torch fuel. Use a cotton rag to wipe excess paste flux off the tubing from the exterior of the joint.

WARNING: Do not leave a cleaned and fluxed joint unsoldered overnight. If you must stop work before soldering, disassemble the joint(s) and remove all the flux. Upon starting work the next day, perform the cleaning and fluxing process from the beginning.

8 Make sure the tubing lengths and fittings are supported or braced so that all tubing remains at the bottom of its respective fitting cup. You are now ready to solder the fitting.



Apply flux to the interior of the fitting.

HEATING THE TUBING

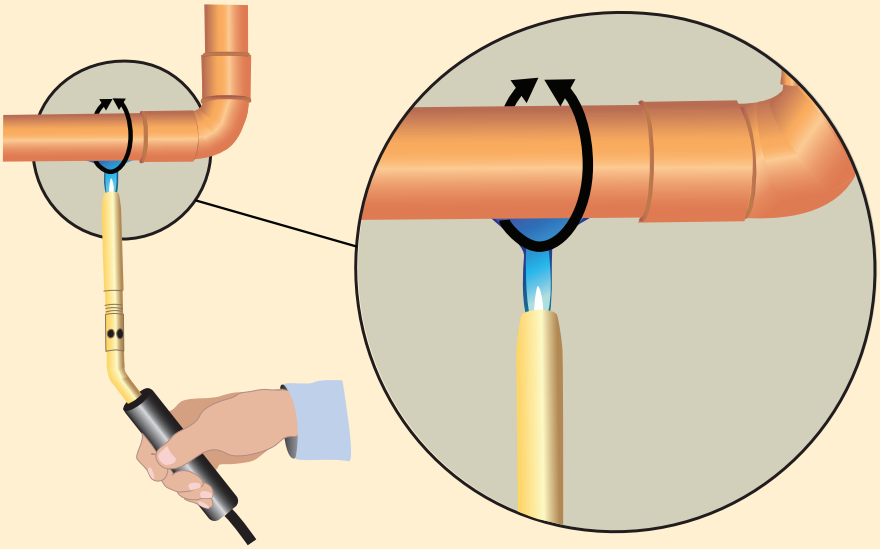
1 Begin by heating the copper tubing outside and just beyond the fitting. This brings the initial heat into the fitting cup and provides even heat to the joint area. If the joint is vertical, be sure to heat the tubing around its entire circumference. If the joint is horizontal, heat the bottom and sides of the tubing. Do not heat the top of the tubing, to prevent burning the flux. The natural tendency of heat to rise preheats the top of the assembly and brings sections of tubing up to temperature. The larger the joint, the more heat and time are needed to accomplish preheating. Experience will determine the amount of preheat time needed. Large-diameter tubing is best soldered with two torches or a multi-orifice torch.

2 Move the flame onto the base of the fitting cup and sweep the flame back and forth between the base of the fitting cup and along the tubing sides to a distance equal to the depth of the fitting cup. Preheat the circumference of the assembly as described above. Again, do not heat the top during this preheating to prevent burning the flux.

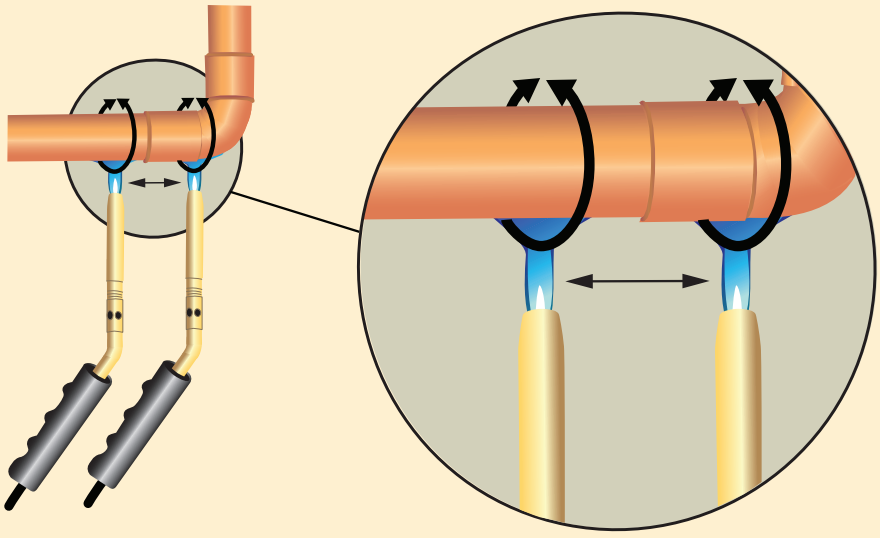
3 Position the flame at the base of the fitting cup, and touch the solder to the joint at the point where the tubing enters the fitting. Keep the torch flame from playing directly on the solder. If the solder does not melt, remove it, and continue preheating. When the solder melts when touching against the fitting and tubing, soldering can begin.

WARNING: Do not overheat the joint or direct the flame onto the face of the fitting cup. Overheating could burn the flux, destroying its effectiveness, and preventing the solder from entering the fitting properly.

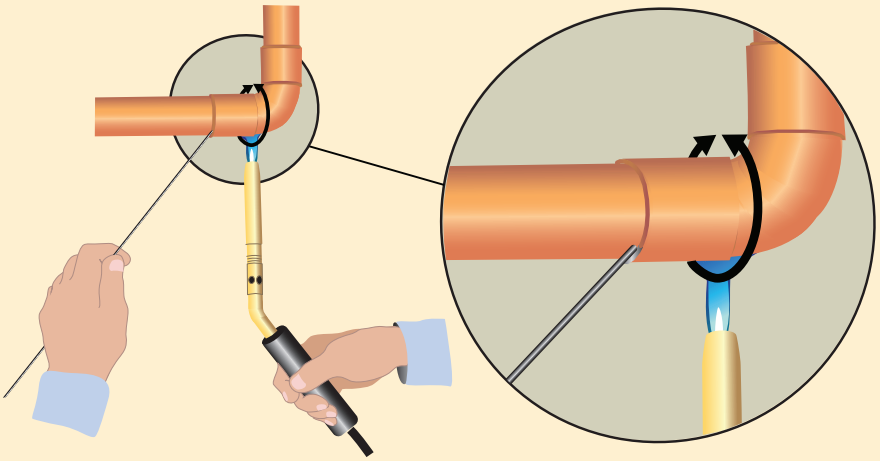
How to Heat the Tubing



◀ Preheat the tubing around the bottom and sides about one cup-length away from the fitting.



▶ Preheat the fitting, starting from the base of the cup and sweeping out to the previous preheat zone.



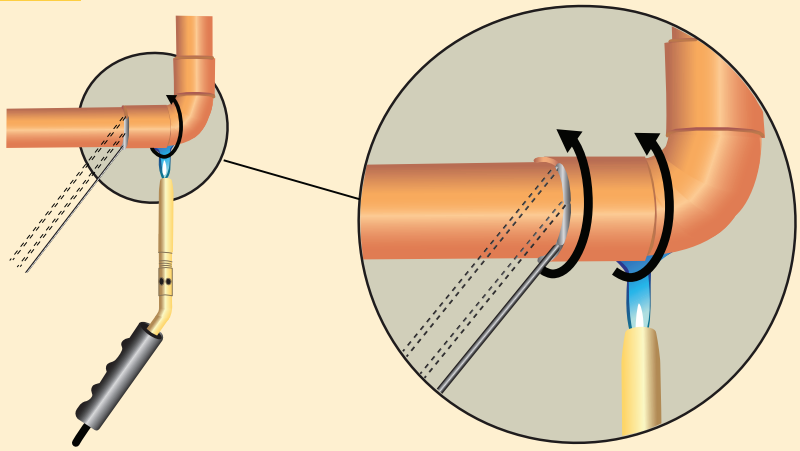
◀ Rather than putting the flame directly onto the solder, preheat the area where the pipe meets the fitting, then touch the solder to it.

APPLYING THE SOLDER

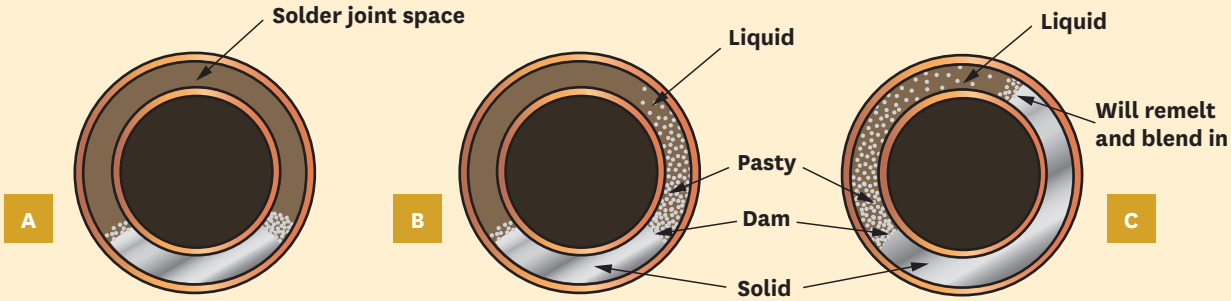
FOR JOINTS IN THE HORIZONTAL POSITION:

- Start applying the solder slightly off-center at the bottom of the joint. When the solder begins to melt, push the solder into the joint while moving the torch upward along the base of the fitting and slightly ahead of the point of application of the solder. When the bottom portion of the fitting fills with solder, a drip of solder will appear at the bottom of the fitting. Continue to feed solder into the joint while moving the solder up and around to its top or 12 o'clock position, and at the same time move the flame so it slightly leads the solder up to the top of the joint. In general, solder dripping off the fitting bottom is not coming from the bottom of the joint. As the joint fills, excess solder runs down the face of the joint and drips off the bottom. This is a good indication of using the proper amount of solder and a full joint. This allows the solder in the lower portion of the joint to become pasty, form a dam, and support the solder applied above it.
- Move the torch heat and solder to the other side of the fitting and, overlapping slightly, proceed up the uncompleted side to the top and over, again overlapping slightly. While soldering, small solder drops may appear behind the

Applying the Solder



◀ Soldering up the side of the fitting



▲ This sectional view of a solder fitting shows how cooler solder in the base of fitting forms a dam to hold pasty solder in place until it cools.

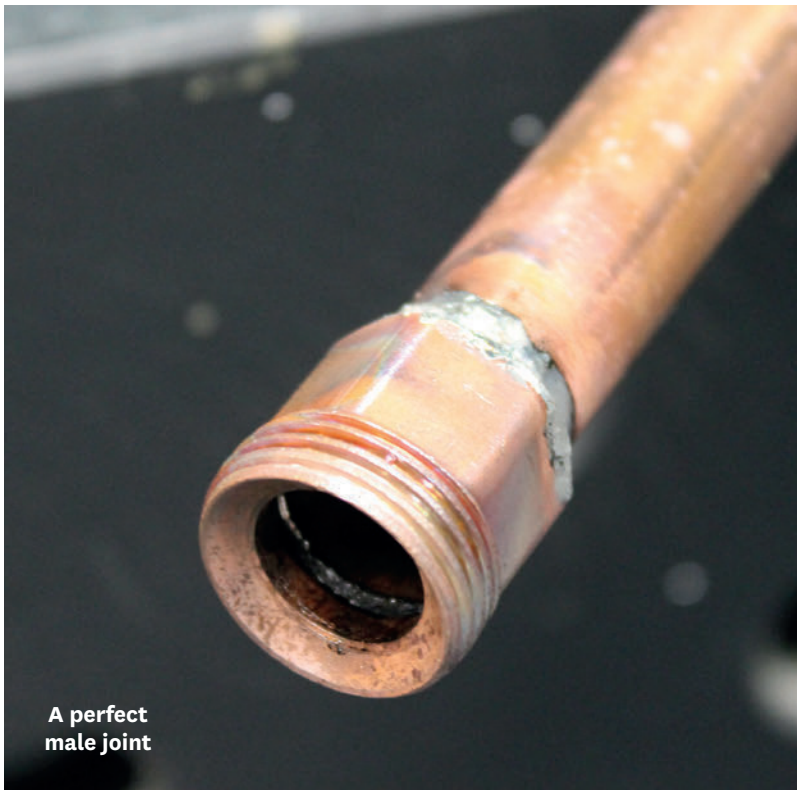
point of solder application, indicating the joint is full to that point and will take no more solder. Because these drops indicate that solder in the upper part of the joint is above the pasty temperature range and in the full liquid state, you want to cool the joint slightly to get back into the pasty temperature range. To do this, relocate the flame to the base of the fitting and apply more solder. Adding this solder will also cool the joint. Throughout this process you are using all three physical states of solder: solid, pasty, and liquid. Remember that you want to control the state of the solder: cooler solidified solder at the bottom of the fitting, pasty transitional state above the solid, and liquid solder at the point of application to allow the solder to be drawn into the fitting. Beginners often apply too much heat and cannot get the solder to stay inside the fitting because it is too liquid.

FOR JOINTS IN THE VERTICAL POSITION:

- After preheating, make a series of overlapping circular passes, feeding in solder and starting wherever is convenient. Stop applying solder when you can see the joint is filled and it will take no more solder. Vertical joints are the easiest to start on.
- Since vertical joints are the easiest to make, it is often wise to plan the job so the maximum number of joints are vertical. Plumbers often preassemble sections of tubing and fittings on a bench or in a vise where it is more convenient and comfortable to work.

FOR FITTINGS WITH A HORIZONTAL OR CUP-INVERTED JOINT:

- Begin soldering the bottom-most joint first, since the heat applied to it will preheat the joints above it. If you solder the upper joints first, you will melt the solder out of them when you begin soldering the lower joints, as the convected heat rises. By soldering the lowest joint first, you not only preheat the joint(s) above it, but you have total control of the heat input to this joint. If you overheat this joint, the solder will be too thin (runny) to be held in place by capillary attraction, and it will run out. Just the right amount of heat lets the solder be drawn up into the joint. After the lowest joint is done, the side or top joint will then be ready to solder. Apply a little more heat to it, and run the solder around the ring where the tubing meets the fitting on the side, then repeat on the top joint.
- In all cases, trying to improve the integrity of a soldered joint by loading additional solder where the tubing enters the fitting is pointless. The strength of the joint is the solder bond between the inside of the fitting and the outside of the tubing (inside the fitting). If the joint was clean and was properly fluxed and heated when the solder was applied, it will hold.



A perfect male joint

FINISHING THE JOB

- Allow the assembly to air-cool without disturbing it. Do not spray it with water or dip the fitting in water, as this can cause cracking.
- Let the joint reach room temperature, then take a clean, cotton rag dipped in water or alcohol and wipe the flux residue from the joint. Wiping the joint while the solder is still molten can lead to joint cracking and is not recommended. Excess solder should be removed with the torch while the joint is still hot. The illustration on page 175 shows what a perfect male joint should look like.
- Test the completed joint for leaks, and flush the tubing lines to remove the remaining flux.

SOLDERING TUBING TO A VALVE

When soldering tubing to a shutoff valve, it is best to remove the valve stem before beginning work because heat from the torch can damage washers or packing material in the valve. Remove the valve stem by turning the packing nut counterclockwise with a wrench. Some ball valves contain Teflon seals that can withstand soldering temperatures for a short time, so there is no need to disassemble the valve.

DEALING WITH WATER IN THE TUBING

Soldering must be done in tubing and fittings that are free of water.

Here are some methods and considerations about drying a pipe when the line has been in service:

- **Open taps above and below the joint to help the tubing drain.**
- **Remove pipe straps on each side of the joint to permit bending the tubing down to let water run out.**
- **On vertical lines containing water, use a short length of ¼-inch hose to siphon out the water so the water level inside the line is at least 8 inches below the joint.**
- **Using paper towels and a stick, dowel, or long screwdriver, remove all moisture and water drops within 8 inches of the soldering area.**
- **Whenever you see steam rising from a fitting after sweating, there is a very good chance that water in the lines has spoiled the joint. Take it apart, fully drain the lines, and begin again.**
- **Valves on the lines to be soldered may not shut off completely, or it may be impossible to drain the line enough to prevent all water from entering the soldering area. To keep this water away, stuff fresh white bread (cut off crusts because they dissolve slowly) into the line(s) to form a plug and push it 8 inches back into the line away from the fitting (you have limited time with this technique). Then assemble the copper tubing to the fitting and complete the solder joint. Flush out the bread when the joint is complete by running water through the line.**

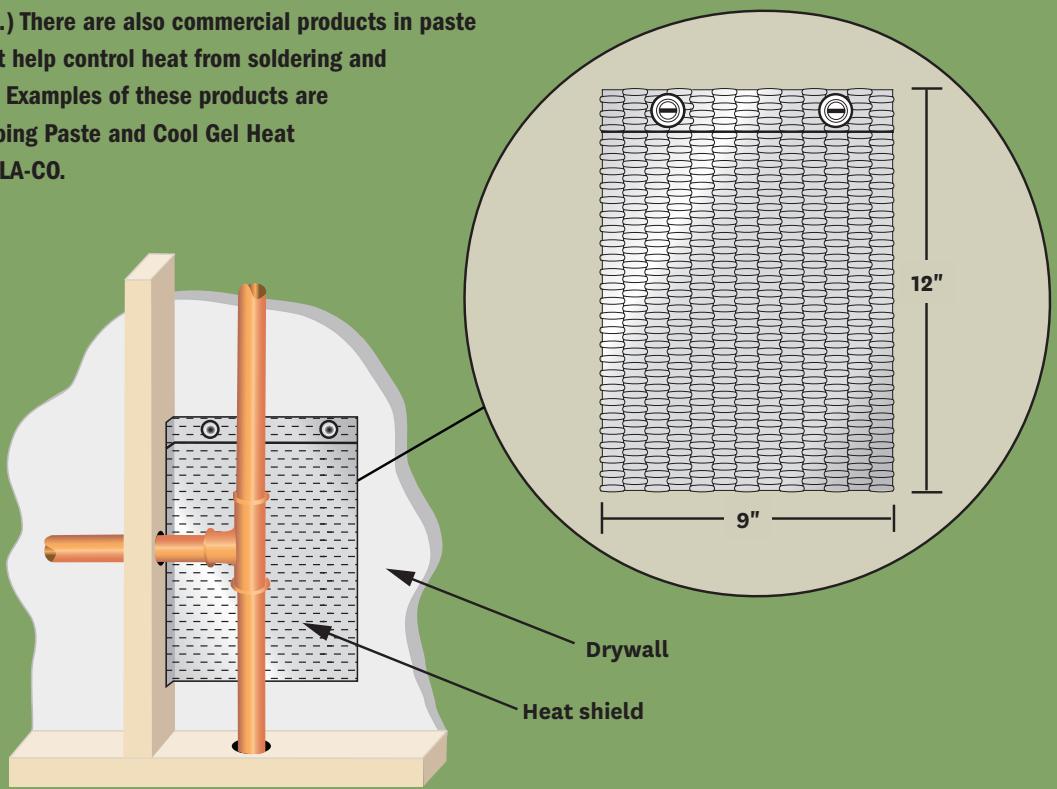
Troubleshooting Tips for Soldered and Brazed Joints

Although soldering and brazing operations are inherently simple, the omission or misapplication of any single part of the process may mean the difference between a good joint and a failure. Faulty joints usually result from one or more of the following factors:

- Improper joint preparation prior to soldering
- Lack of proper fitting and tubing support during soldering or brazing may cause wiggling of the joint while the filler metal is molten; non-concentric joint alignment may lead to gaps in filler metal
- Improper heat control and heat distribution through the entire joining process
- Improper application of solder or brazing filler metal to the joint
- Inadequate filler metal applied to the joint
- Sudden shock cooling and/or wiping the molten filler metal following soldering or brazing

Protecting Flammable Surfaces

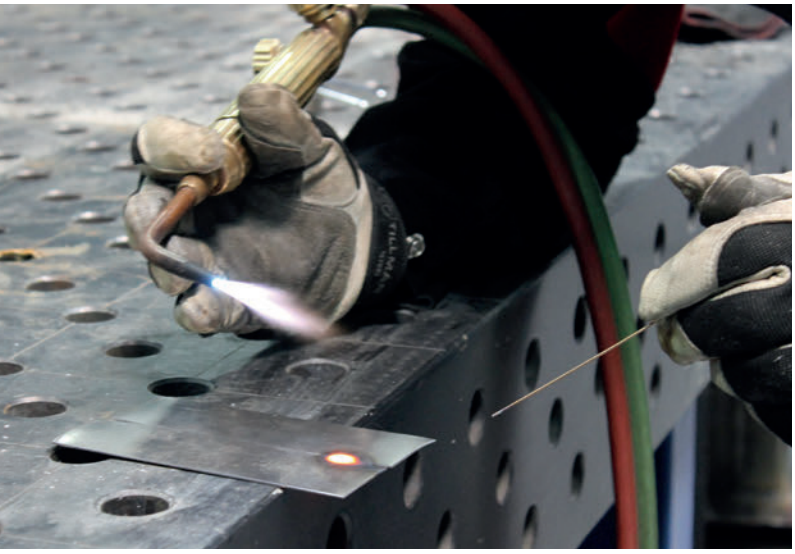
Use a commercial woven-glass heat shield to keep the torch flame off of building materials, or use a piece of heavy steel or aluminum to do the same thing. (Old-timers used pieces of asbestos, which worked even better.) There are also commercial products in paste and spray form that help control heat from soldering and brazing operations. Examples of these products are Bloc-It Heat-Absorbing Paste and Cool Gel Heat Barrier Spray from LA-CO.



► Use a heat shield when working in close quarters.

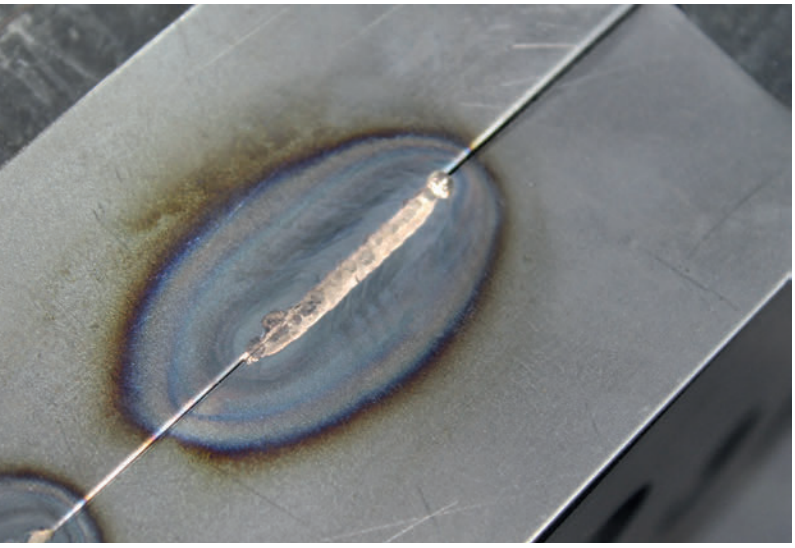
Braze Welding

Brazing and soldering differ from welding in that the heat produced when brazing or soldering does not melt the base metals. Rather, the heated work draws a filler material into the joint through capillary attraction. In braze welding, the joints of two pieces of metal are open to the welder, and filler material is deposited into the joints, joining them together.



1 To begin braze welding, clean the metal thoroughly. For metal over ⅛ inch thick, grind a 46- to 60-degree bevel in both sections. This produces a wide groove that is larger than the groove used in most welding projects. Thin metals like those shown here do not need a groove for proper adhesion.

2 Hold the torch about ¼ inch away from the work. The goal is to heat both sides of the joint evenly. Circle the torch and begin adding the filler material. Judge your speed by how well the filler material flows and adheres to the metal.



3 Here is a finished section of a braze-welded joint. The braze material should flow smoothly into the base metals on both sides of the joint. For added strength, you can make another pass over the first bead.

SOLDERING A SYRUP PAN

Stainless steel maple sugaring pans are often replaced when they develop leaks in the corner joints. This is both costly and unnecessary. Soldering depends on capillary action to draw filler metal into the joints and then solidifies as it cools.

1

This maple syrup pan developed a leaky corner when the pan became too hot. This melted the solder and created a leak. Before the pan could be repaired, it needed to be thoroughly cleaned with denatured alcohol to remove carbon deposits from the burned syrup. Trying to skip this step will make the soldering process frustrating, as capillary flow of the filler metal will be difficult to achieve.

2

Fluxes further clean the base metal surfaces and promote capillary action. Here we applied flux to the damaged area with a small brush, then heated it with a propane torch which allowed the flux to penetrate into the cavities.

3

We used a food-grade, lead-free solder since the pan is used for making syrup. We followed the heat of the propane torch and created a puddle by pushing the solder into the area to be filled.

Despite the size of the original leak, we were able to seal the pan and return it to service. After the pan was reinstalled, we filled it with water to verify the leak had been fixed.

EIGHT

WELDING TASKS AND TIPS

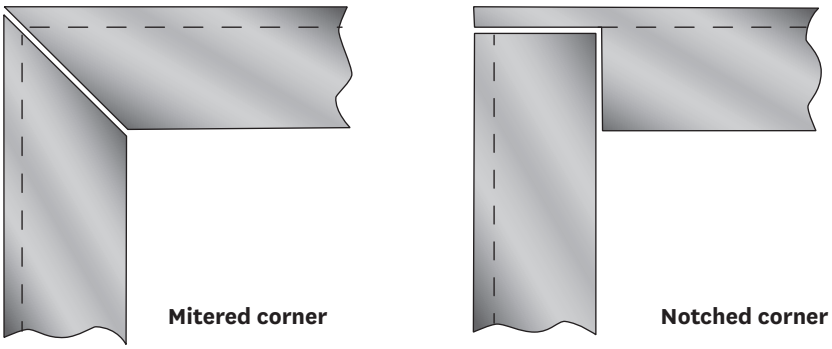
This chapter contains instructions for performing some of the most common welding tasks. There are details on how to make rectangular frames, put legs on a table, and make a three-dimensional solid frame. There are also instructions for repairing cracked truck frames and damaged welding on vehicles. In addition, there is a section on pipe and tubing repairs and tools. And there are expert tips on controlling distortion while welding.

Corner Treatment for a Welded Rectangular Frame

Mitering and notching are two common ways to make angle iron corners for a rectangular frame. Both methods work, but a beginner might find notching easier because it is more dimensionally tolerant. Following welding and grinding, either fit-up style will result in a good finish.

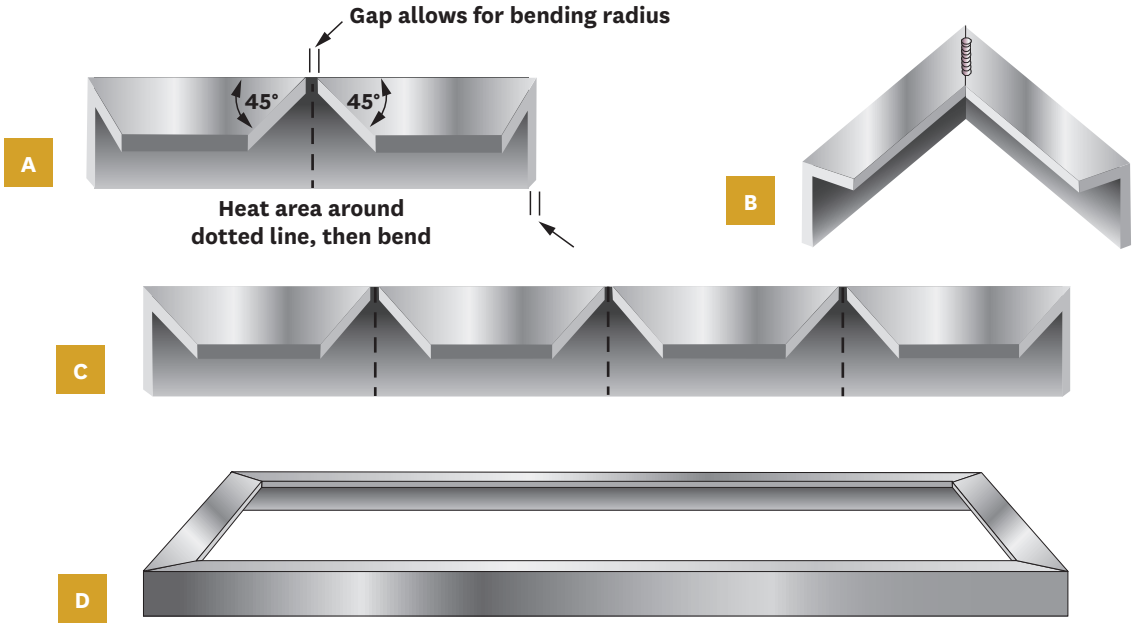
SINGLE-PIECE FRAME

You can make a rectangular frame from a single length of angle iron. This approach lends itself to production work and works well when a notching machine is available. Getting the correct bend allowance gap is critical, because it provides the extra material needed to go *around* the outside of the corner when the bend is made. Begin by setting the bend allowance gap to slightly less than the thickness of the angle iron and go from there.



A mitered (left) and notched (right) frame corner

NOTCHING AND BENDING TO MAKE A SINGLE-PIECE FRAME

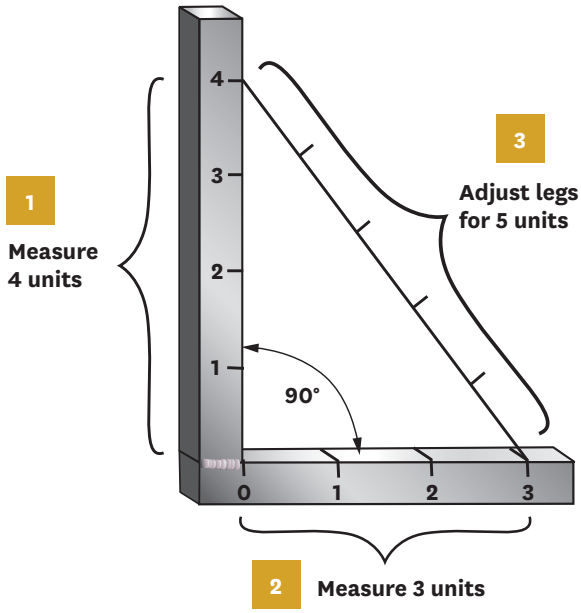


(A) corner detail before bending; (B) corner detail after bending, welding, and grinding; (C) notched angle iron frame ready for bending; and (D) completed frame

The Best Way to Check if Corners Are Square

Check for equal diagonal lengths between opposite corners with a steel measuring tape. On large frames use a carpenter's square, on smaller ones use a machinist's square. When the diagonal dimensions are equal, the frame is square.

If the sides of the completed frame must be plumb (perfectly vertical) and level (perfectly horizontal), a large level can be used to check for plumb and level; if both the vertical sides are plumb and the horizontal sides level, the frame is square. When welding a very large L-shape, where a square is too small and there are no diagonals to measure, use the 3-4-5 triangle method: (1) measure off four units (feet, meters, or other units) on one leg, and (2) measure off three units on the other leg, (3) then adjust the hypotenuse, the longest side of the triangle, until it equals five units. This procedure makes a perfect right triangle.



A 3-4-5 triangle can be used to set members at a right angle.

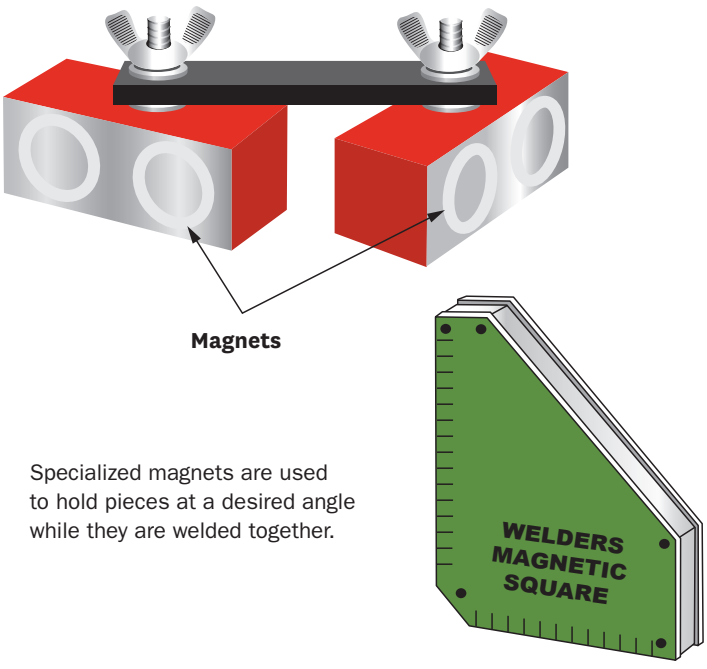
Tips for Welding Square Frames

In decreasing order of effectiveness:

- Secure members in a rigid fixture and weld them in it.
- Clamp members to a steel table and then weld them.
- Use a fixture to hold parts for tacking, then weld the tacked parts *outside* the fixture. This fixture can be as simple as a sheet of plywood with wood blocks fixed to it to hold the work in place while the tack welds are made.
- Use Bessy-type corner clamps. Hint: Begin by tack welding each of the corners together, using the clamp each time, then check for square. Bend the assembly back into square, if necessary. If the tack welds are not too large, you'll be able to straighten the frame with moderate force — by hand and without hydraulic jacks. Begin final welds at *opposite* corners.

WARNING: Making a final weld one corner at a time in a corner clamp will bring poor results — the final two corner pieces are not likely to meet.

MAGNETIC CORNER TOOLS



Specialized magnets are used to hold pieces at a desired angle while they are welded together.

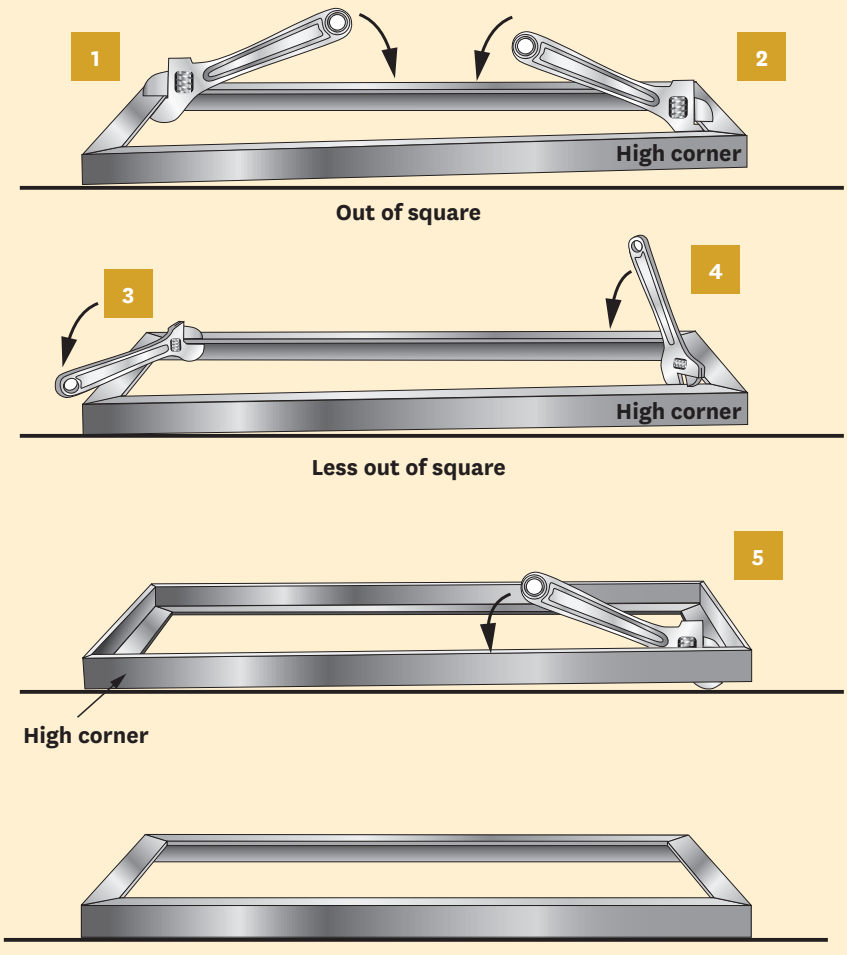
- Use magnetic corner tools. These are effective only for light sheet metal, as they lack the strength to resist weld-induced distortion forces, even with light angle iron.
- When working in the field or with large and heavy members, lay up the members square and level on a concrete floor (you may need to shim them to get them flat), tack them together, and then weld them. Recheck for frame to confirm it is square and flat after making each tack, and bend members back to square and flat *before* making the next tack or weld. Keep the tacks small: If they are too large, you won't be able to bring the frame back into square by hand or with the tools you have on hand.

WARNING: Welding directly on concrete can cause it to explode violently from moisture inside the concrete expanding. Shimming the work off the floor eliminates this hazard.

- To control distortion, weld opposite corners first, and weld the *same* relative corner or side position in the exact same sequence on all four corner joints. First weld all outside faces, then all top corners, and, finally, all bottom faces. Make each weld in the same relative direction from the outside of the frame to its inside, or vice versa. Also, give each weld a moment to cool before making the next.

Troubleshooting a Frame

If you have welded a rectangular frame of angle iron (not rectangular tubing) that does not lie flat, follow these steps to bend the horizontal face of the frame to flatten it. Use an adjustable wrench or fabricate a tool of your own.



One method of adjusting an angle iron frame to lie flat

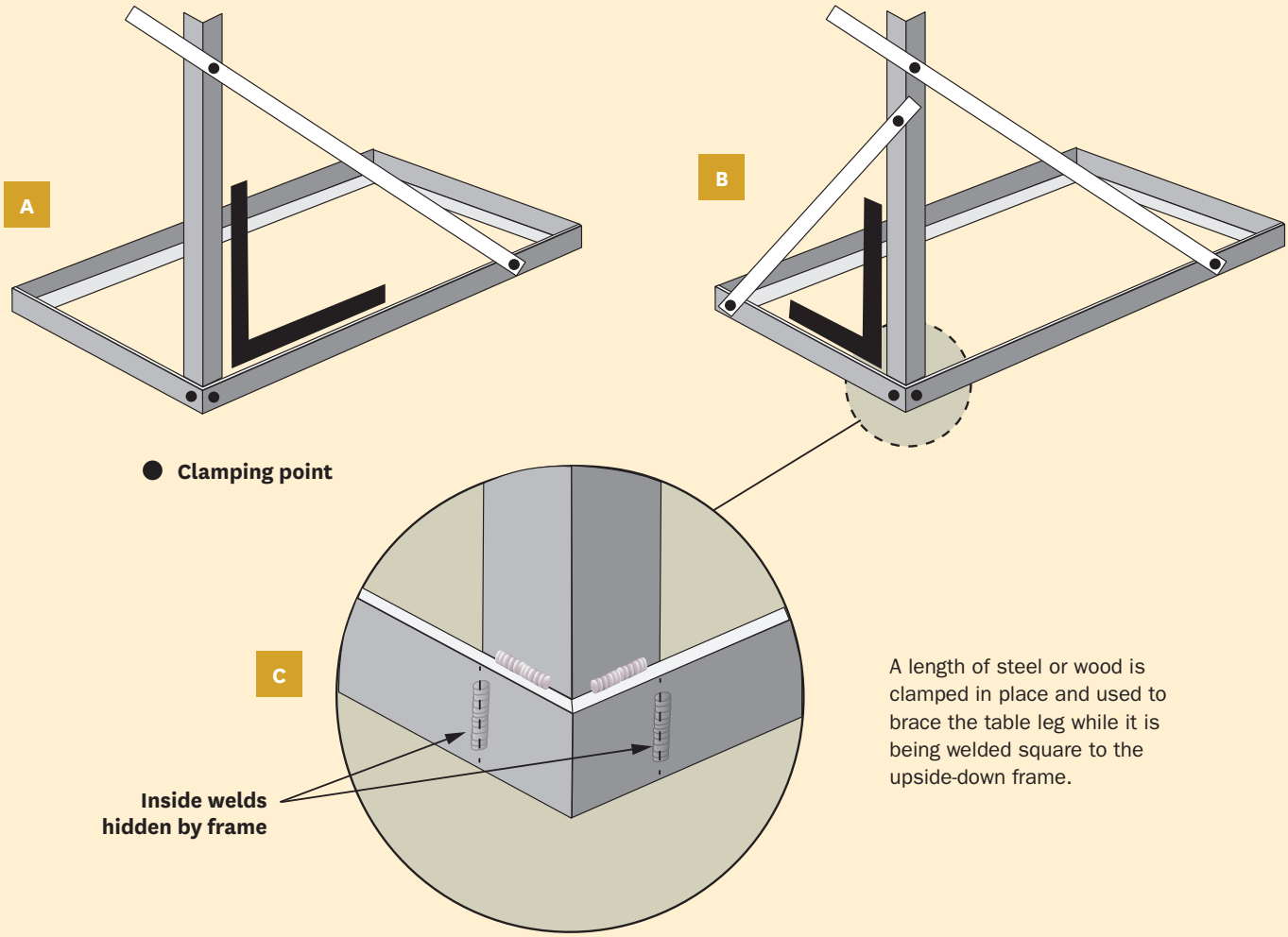
Mounting Table Legs

To weld supports to a rectangular frame — as in making a table — follow the steps below.

Put the table frame upside down on a flat surface, such as the top of the welding table. Use two clamps to lightly secure a leg to both sides of the frame corner.

Using a carpenter's square (framing square), adjust the leg so that it is perpendicular to the frame. Using a length of steel or wood and two clamps, brace the member in the square position. Repeat the same process on the other side of the leg. Fully tighten the two clamps holding the leg to the frame. Recheck for square in both directions, and adjust as needed, then weld the leg to the frame. Repeat this for each leg.

Welding Table Legs so They Are Square

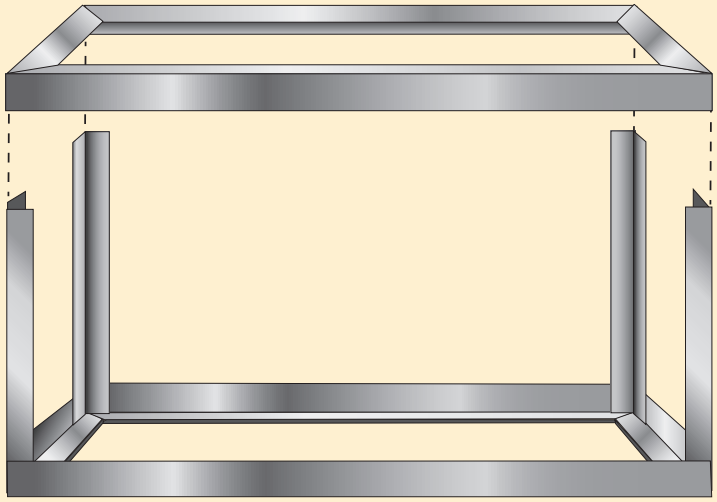


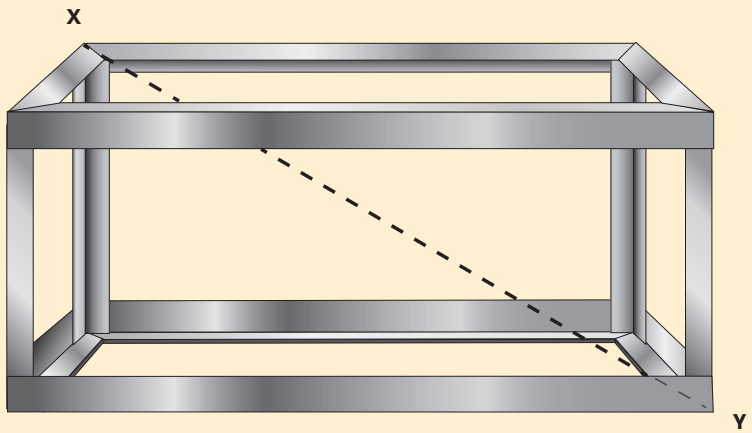
A length of steel or wood is clamped in place and used to brace the table leg while it is being welded square to the upside-down frame.

Box Frames

To make a rectangular solid box frame, make the upper and lower frames as described previously. Use clamps to secure the four verticals to the lower frame, making them square to the lower frame. Place the completed upper frame over the legs. Make whatever compromises and adjustments are needed to the verticals so they meet the upper frame. Some tweaking may be necessary. Note that all opposite diagonals, like dotted line X-Y in the illustration below, will be the same length in a rectangular box. Clamp the verticals to the upper frame. Tack all of the joints, keeping the components square. Then, weld all of the joints. This method works equally well with angle iron and rectangular tubing.

Fabricating a Box Frame





Two rectangular frames connected squarely by four vertical pieces of angle iron makes a sturdy frame for a box.

THE PORTABLE PIG ROASTER

As you gain skill welding, you're likely to view the scrap pile as a gold mine of opportunity. Old oil tanks for example, make excellent smokers and roasters, and making it portable will make you the hit of the neighborhood. In this project we took an existing oil tank roaster and retrofitted it with a mobile home axle and a tongue with a ball hitch.

1

Our project began with an old pig roaster made from a 275-gallon oil tank. A 2-inch-square tube frame was already on it, but it was difficult to move. We turned the roaster over to make the axle and tongue installation easier.

2

Because it's imperative that the frame, axle, and tongue are all perfectly aligned for towing, take your time in marking out the mounting locations. A framing square and tape measure are essential for this. As with all welding projects, prep the surface by grinding before welding and double check your measurements after tack welding.

3

With one end of the tongue tack welded, confirm the opposite end is square and tack that end as well. Note that the corners on square tubing are rounded so the joint is actually a flare bevel groove not a perfect right angle fillet. Be sure that the weld penetrates into the groove, and take multiple passes to ensure a quality bond.

4

We opted for a ball hitch for this trailer. While we could have bolted the hitch on, we decided to use a series of plug welds (both sides and top) to attach it to the tongue. Note the use of a locking clamp to keep the hitch aligned.

5

To add strength to the tongue, a 3-foot brace was placed on each side at a 45-degree angle. Note that the adjoining surfaces have a clean, tight fit, making it easier to produce a quality weld.

6

Note that all four sides of the tube are welded for greater strength.

7

Since this trailer isn't going to be used on the road, we opted to mount the axle directly to the frame without any suspension components. Unfortunately, the axle mounts were wider than our existing frame, so we carefully removed the axle mounting brackets with a cutting torch and then rewelded them on the frame in the proper location.

8

Once the axle was welded on the bottom, the roaster was flipped over and welded from the top as well.

The finished pig roaster is ready to cook!

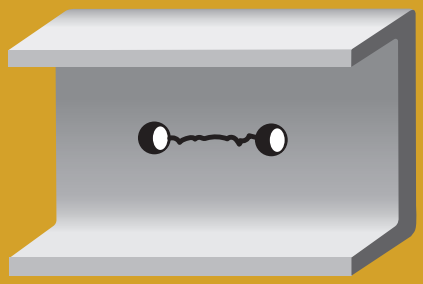
How to Repair a Cracked C-Channel Truck Frame

Many of the C-channel frames of modern tractors and heavy trucks carry a label that warns against cutting or welding them. To save weight, manufacturers use thinner, lighter steel U-channel members with a special heat treatment to provide extra strength. Welding and torch cutting these members destroys the strength of the factory heat treatment. Do not weld, flame cut, or drill these members if they have not failed. If you have to mount something on the frame, use any extra (unused) existing holes put in at the factory. However, if C-channels must be repaired, minimize welding on them.

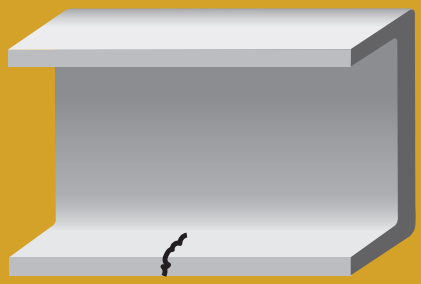
Use the following steps to prepare the weld:

- Clean the repair area by steam cleaning and scrubbing the entire area surrounding the weld. (This cleaning is particularly important for waste hauling vehicles.)
- Use an oxy-fuel torch to dry the area and remove any remaining mill scale.
- Finally, wire brush the area down to shiny metal.
- Compare your failure with those shown in the illustration on the right to determine which example your frame failure matches best, and follow the repair steps for that example.

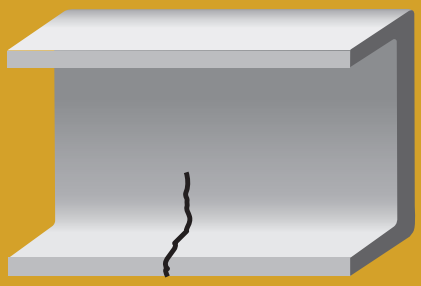
Typical Truck Frame Cracks



CASE I



CASE II

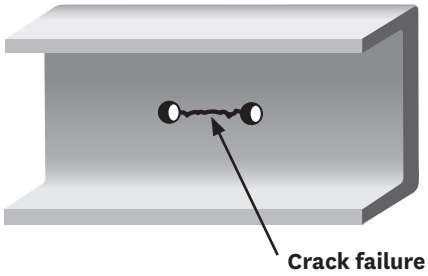


CASE III

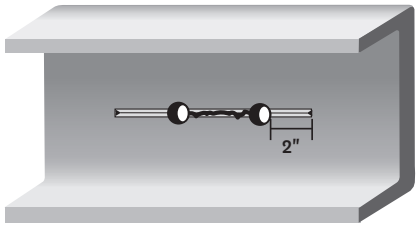
CASE I

HORIZONTAL CRACK ALONG THE WEB BETWEEN FACTORY-DRILLED HOLES

Horizontal crack in truck C-channel between factory-drilled holes in web. This is a common case and cracks as long as 10 inches can occur.



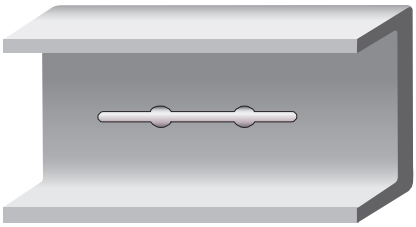
1 Grind a V-groove to within 1⁄16 to 1⁄8 inch of the thickness of the web steel along the path of the crack and extending 2 inches beyond the initial crack on each end. Locate this V-groove on the inside of the C-channel.



Grind out crack

2 Clamp a copper backing plate to the back of the groove to protect the back of the weld from atmospheric contamination.

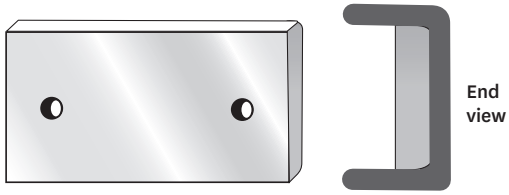
3 Using SMAW low-hydrogen or iron powder electrodes, fill the V-groove with weld metal. Use enough current for a full-penetration weld.



Fill V-groove

4 Grind the weld flush, making sure to leave the ground surface as smooth as possible. Any irregularities or scratches are stress-raisers. Also grind on the outside of the channel, if necessary, to make it flat.

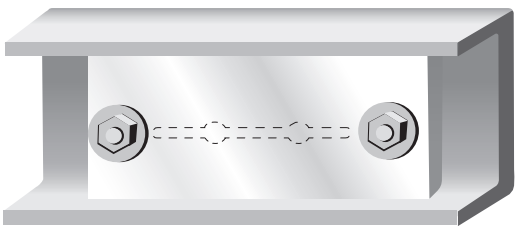
5 Cut and fit a ½-inch-thick carbon steel reinforcement plate on the inside of the web, extending at least 6 inches beyond the ends of the weld repair. Grind this plate on the lower and upper edges so it fits *tightly* against the web and edges of the flanges for its entire distance.



Round corners of reinforcement plate to fit tight inside C-channel

6 Using existing factory-drilled C-channel holes, if possible, secure the reinforcement plate to the web with bolts matching the diameter of these holes. Holes are usually sized ½, 9⁄16, or 5⁄8 inch in diameter. Use a washer under each nut. If no holes are available, drill your own. The repair is complete. No additional welding is needed.

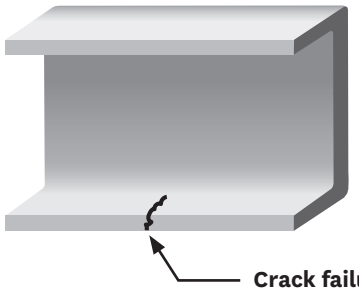
COMPLETED REPAIR



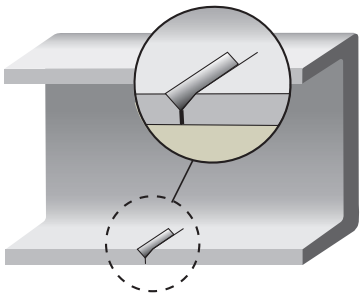
CASE II

CRACK ON BOTTOM FLANGE PERPENDICULAR TO WEB ONLY

Crack on bottom flange perpendicular to web only

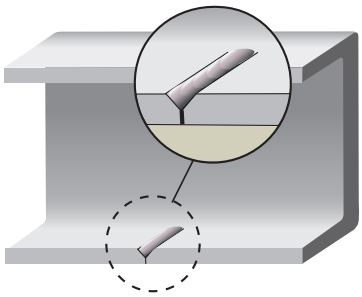


1 Grind a V-groove half-way through the thickness of the flange along the path of the crack.



Grind out crack

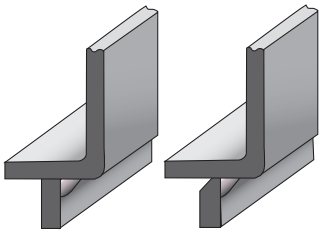
2 Using SMAW with a low-hydrogen or iron powder electrode, fill the V-groove with weld metal. Use enough current for full penetration of the flange metal.



Fill V-Groove

3 Grind the weld flush, making sure to leave the ground surface as smooth as possible. Any remaining surface imperfections are stress-raisers. Also grind on the inside of the flange, if necessary, to make it flat.

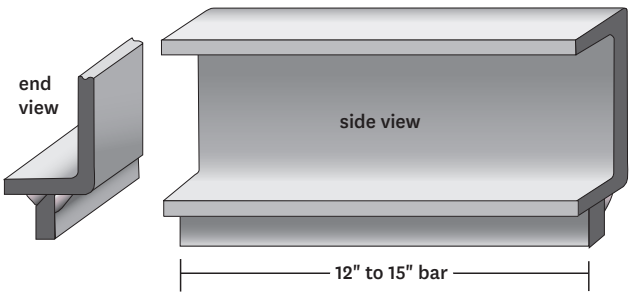
4 Cut a ½ × 1½-inch reinforcement bar from mild carbon steel 12 to 15 inches long. Center the bar on the crack, and weld it on the middle of the flange, using a SMAW low-hydrogen or iron powder electrode. The 1½-inch dimension of the bar is vertical.



Add reinforcement bar and grind bevel groove

5 Using a grinder, gouge a bevel groove through the unwelded side of the reinforcement bar to sound weld metal on the other side. Place a fillet weld in the gouged groove, using SMAW with a low-hydrogen or iron powder electrode to secure the other side of the reinforcement bar. Do *not* make welds perpendicular to the length of the channel at the ends of the reinforcement bar.

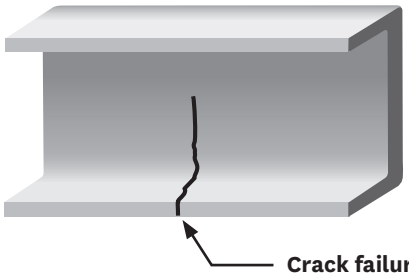
COMPLETED REPAIR



CASE III

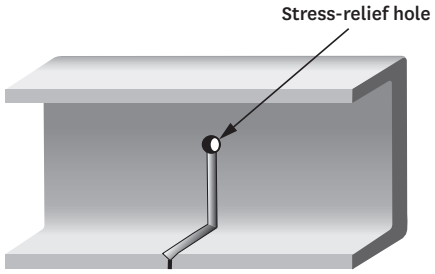
CRACK ON BOTTOM FLANGE PERPENDICULAR TO WEB AND EXTENDING UP INTO WEB

This is what happens when Case II is left uncorrected. The crack begins on the bottom flange and extends into the web of the channel.

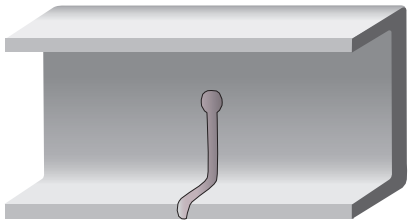


1 Grind out the crack with a V-groove halfway through the thickness of the flange along the path of the crack.

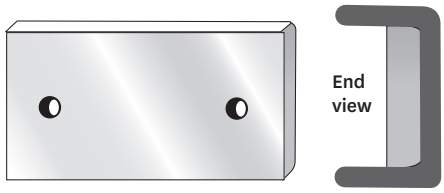
2 Drill a ⅜- to ½-inch-diameter hole at the end of the crack in the web to relieve stress.



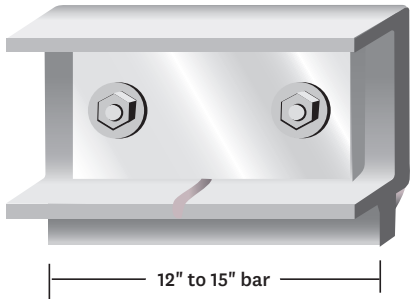
3 Grind out the crack and fill in the resulting V-groove.



4 Prepare reinforcement plate to fit tight inside C-channel.



5 Bolt a reinforcement plate inside the C-channel and weld a reinforcement bar to the bottom.



COMPLETED REPAIR

TRADITIONAL C-CHANNEL REPAIR

Another, more traditional, C-channel repair approach is to weld reinforcement plates to the web instead of bolting them or to weld a reinforcement bar along the bottom flange, but this is less commonly done today. If you choose welding instead of bolting, be sure to place welds *parallel* with the channel. Do not place any welds perpendicular to the channel. Welds perpendicular to the channel concentrate stresses on just one section of the weld. This is because the end welds on the patch plate prevent beam stress from being distributed evenly along the weld length. They become a new stress-raiser and will produce near-term failure.

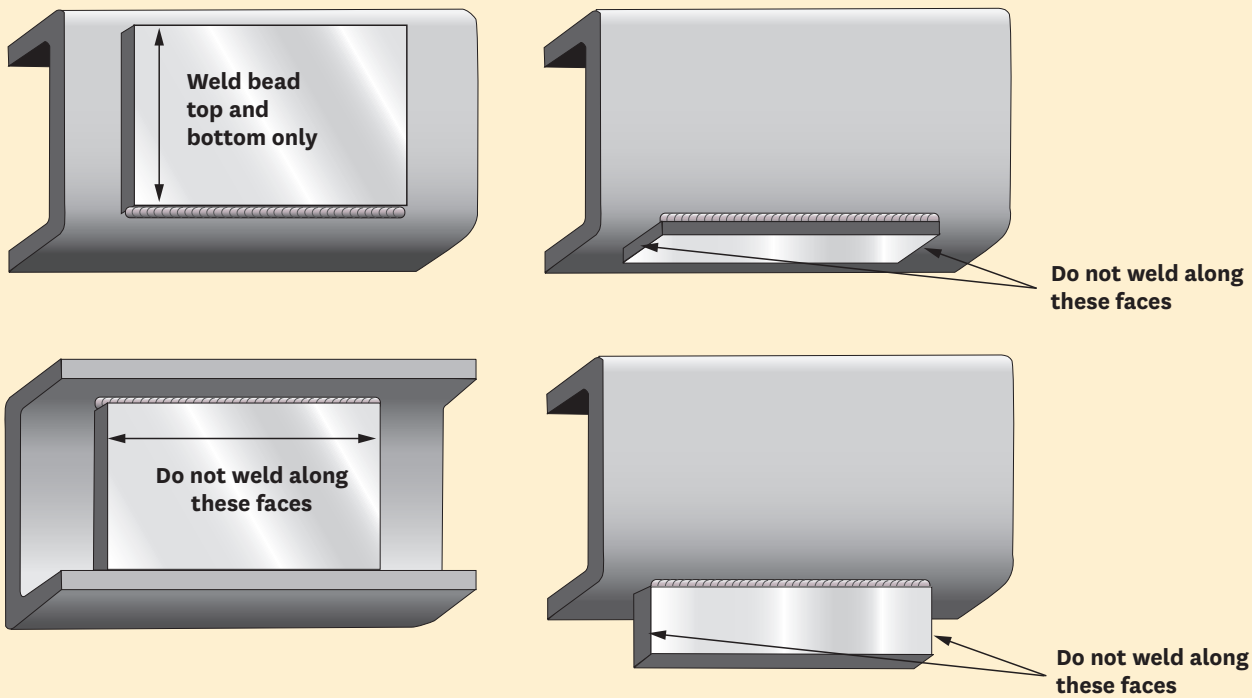
WARNING: Keep in mind that these failures occurred in the first place because the member was stressed beyond its design capacity by excessive loads and fatigue. Dump truck body action stresses, hydraulic cylinder loads, road vibration, and truck overloading all contribute to failure. *Failure is likely to happen again,* usually in the next-weakest location because the member is subject to the same load conditions that caused the initial failure.

WELDING HIGH-STRENGTH STEEL

Oxyacetylene welding on high-strength sheet metal on newer-model cars leads to cracking. Instead, use MIG welding: Begin the weld bead on the outside edge of the crack and work toward the inside. This keeps the inherent weakness of the bead-ending crater away from the metal's edge, where it would act as a stress-raiser and lead to a new failure. On galvanized body parts, use ER70S-3 electrodes, as they contain less silicon than ER70S-6 electrodes. Silicon contributes to cracking when mixed with zinc.

Welding Reinforcement Plates to C-Channels

Welds parallel to C-channels are acceptable; perpendicular welds are not



REPAIRING A FARM TRAILER

This old utility trailer, made from the bed of a 1950s Chevrolet pickup truck, was left in the woods to rot after the wooden bed had decomposed and one of the steel cross-members gave way. Resurrecting this old trailer took less than an hour, and will provide years of faithful farm service.

1

The area where the cross-member support was needed had an old rusty bolt in the way. The nut was rusted stuck, so we elected to cut it off with a portable oxyacetylene torch. While we had the torch out, we also cut the angle iron to fit between the side rails of the trailer (for tips on cutting with an oxyacetylene torch, see chapter 4).

2

Trying to weld rusty metal results in a weaker weld. Begin by prepping the surfaces with a wire wheel or grinding disk. When properly cleaned, the surfaces should be shiny and clear of rust. If you're working in the field and don't have access to power tools, using a wire brush or sandpaper is a suitable alternative.

3

For the cross-member repair we used 1½ × ⅛-inch mild steel angle iron. Incidentally, this is the same stock that's commonly used for metal bed frames. An existing metal bracket on the frame provides a solid surface to weld along.

4

The ground clamp on the welder can also double as a work clamp at the opposite end as where you're welding. We used ⅛-inch 6011 general-purpose SMAW rod, though this repair could have been made with MIG or oxyacetylene welder. An initial tack weld allows you to check the fit of your work before proceeding. Tack one end, and then tack the other before cleaning the tack weld and returning to run your final bead.

5

The final bead is only about 2 inches long on each side, but provides strength, thanks to a deep-penetrating weld. Remove the slag and inspect the weld for evenness and quality (see Judging Welds on page 73).

6

With the new cross-member in position, this trailer is ready for a new wooden deck, then back to work on the farm!

Tips for Welding Pipe and Tubing

It is important to understand the differences between pipe and tubing. Pipe usually has a much thicker wall than tubing. This permits pipe to accept threads; the thin walls of tubing cannot be threaded. Another difference is that pipe from ¼ to 12 inches in diameter is specified by its *inside* diameter; pipe 14 inches in diameter and larger is specified by its outside diameter. Tubing is always specified by its *outside* diameter and wall thickness.

PIPE CUTTING METHODS

For most jobs, you will need to cut pipe and tubing to length. Once it is cut, prepare the pipe or tubing by cleaning, grinding, brushing, or beveling the ends.

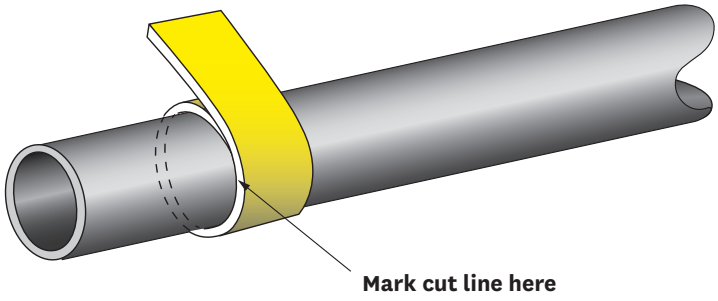
Cutting Methods for Carbon Steel Pipe

Type of Pipe	Method of Cutting
Steel pipe 3" (80 mm) diameter or smaller	Manual wheeled pipe cutter, or wheeled pipe cutter operating in powered threading machine, or portable bandsaw, or oxy-fuel cutting
Steel pipe over 3" (80 mm) diameter	Oxy-fuel cutting, or abrasive cutoff saw

HOW TO CUT STEEL PIPE WITH AN OXY-FUEL TORCH

Cutting small diameter pipe. In cutting small-diameter pipe, the torch remains in the vertical position at all times. First, make a cut from the 12 o'clock to the 9 o'clock position. Then, make another cut from the 12 o'clock to the 3 o'clock position. Rotate the pipe a half-turn and the repeat the same two cuts to cut through the pipe.

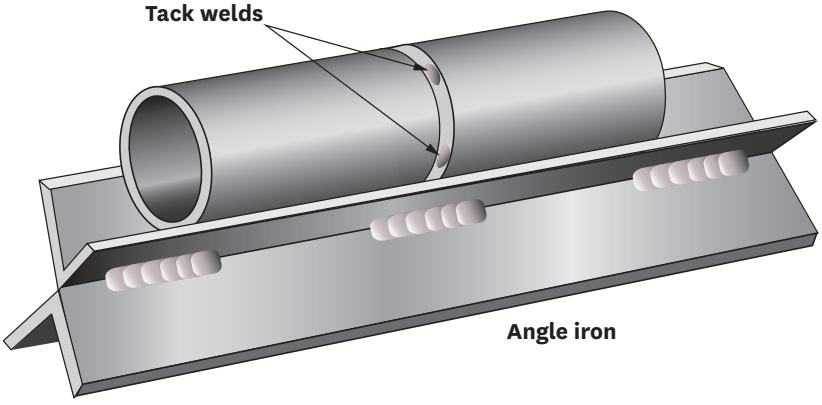
Marking large-diameter pipe. To mark the cut line on large pipe, use a *wrap-around*, which is a length of thin, flexible material — vinyl, fiber, or cardboard — that is wrapped around the pipe one and a half times, as shown in the illustration below. Adjust the wrap-around so that the overlapping layer lies squarely over the first layer. Hold the wrap-around tight with one hand and mark the cut line with the other. A typical wrap-around is 1/16 inch thick by 2¼ inches wide by 48 inches long.



◀ A wrap-around helps you mark a square cut line around the circumference of a pipe.

JOINING LENGTHS OF PIPE

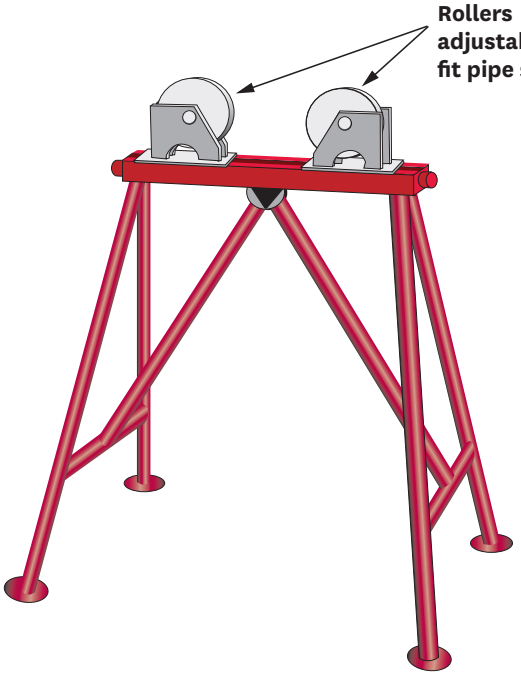
If you need to join two lengths of pipe and want to align them accurately, but you do not have a commercial pipe welding fixture, tack two lengths of angle iron to form a double V-base, as in the illustration below. Many applications will require a longer welding fixture than the one shown. Align the pipes before tack welding, then make the root pass, followed by subsequent passes.



◀ Using angle iron for alignment can ensure accuracy when welding pipe.

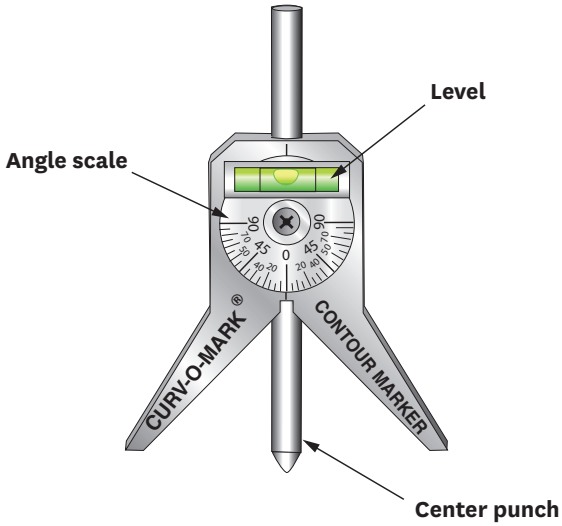
WORKING WITH PIPE

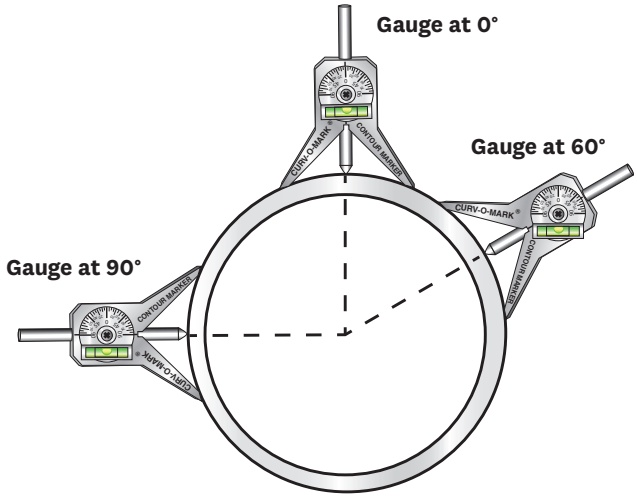
Pipe rollers permit the welder to always be welding in the flat position. The welder welds while a helper rotates the pipe so that the weld area remains on the top of the pipe. When welding in the field, the welder may make the weld in a fixed or stationary position. Using four rollers together keeps the pipes stay in alignment while they are being welded. On very large pipe or castings, a motor-driven positioning device may take the place of rollers.



▲ Commercial pipe rollers on stand

A Curv-O-Mark Centering Head tool locates any angle on the outside of a pipe. Just set the adjustable scale to the angle desired, place the tool on the pipe to the "level" position of the bubble, and strike the built-in center punch to mark the point. The illustration below shows the contour tool locating the exact top, or zero-degree position, the 90-degree position, and the 60-degree position.

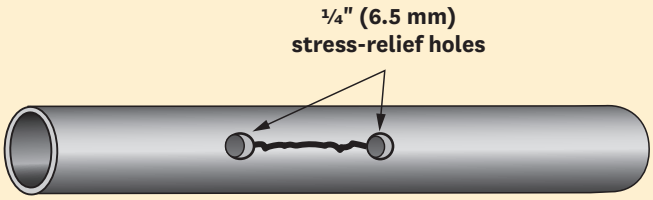




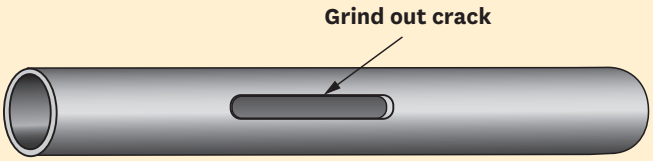
▲ Curv-O-Mark Centering Head tool for locating angular positions around a pipe

Repairing Cracks in Structural Tubing

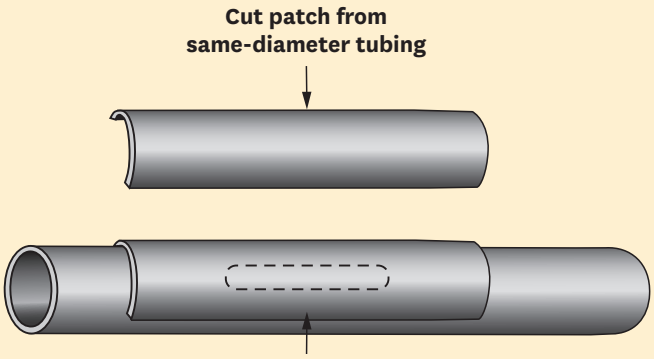
To repair cracked structural tubing (carries no fluid), follow these steps:



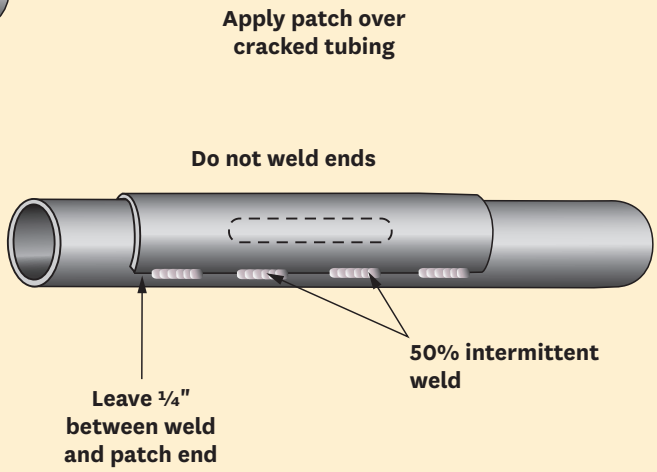
1 Drill ¼-inch stress-relief holes at the ends of the crack.



2 Cut or grind away the cracked area between the ¼-inch holes.



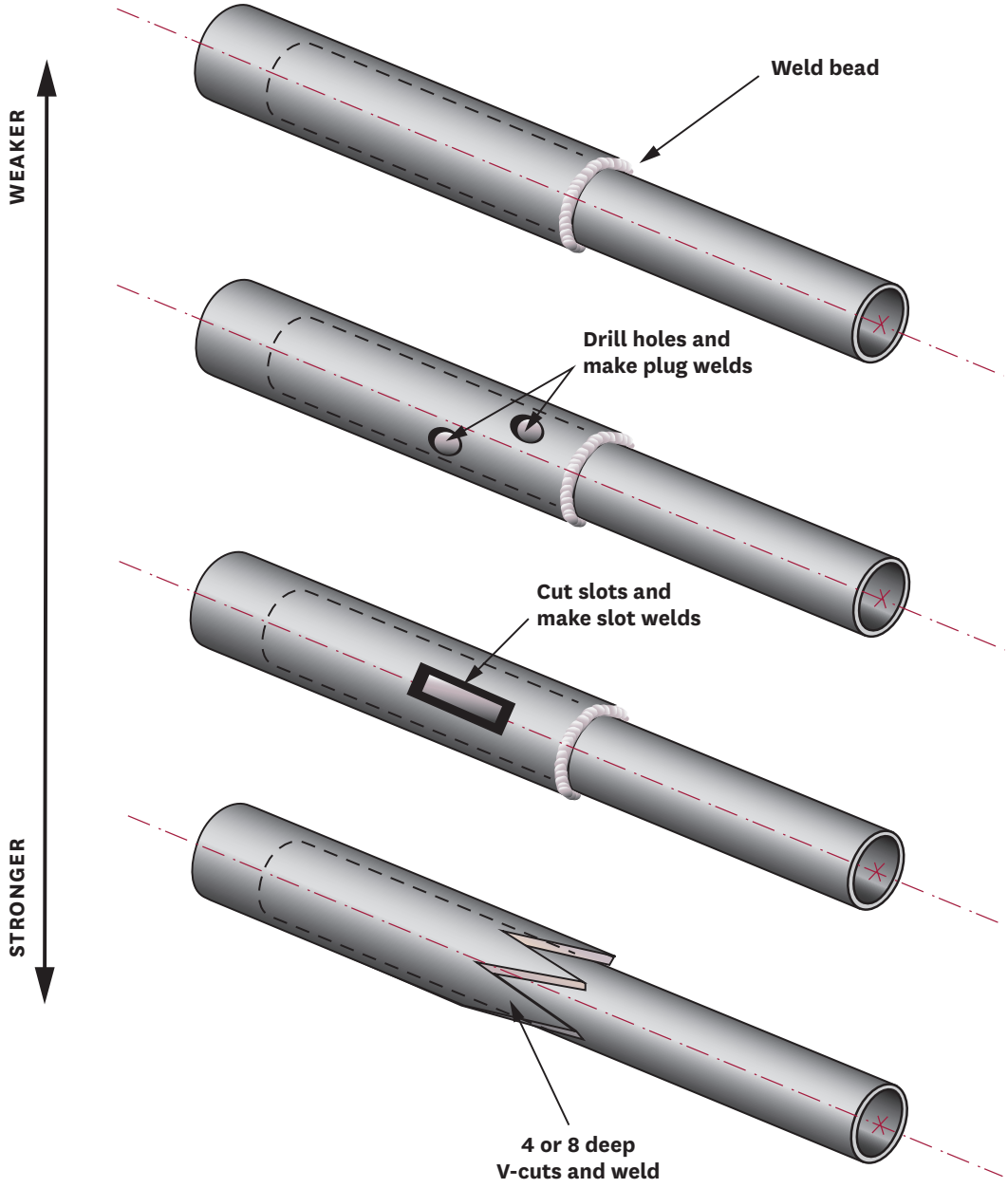
3 Cut a patch out of a similar-sized piece of tubing, and reshape this patch to fit over the cracked tubing area.



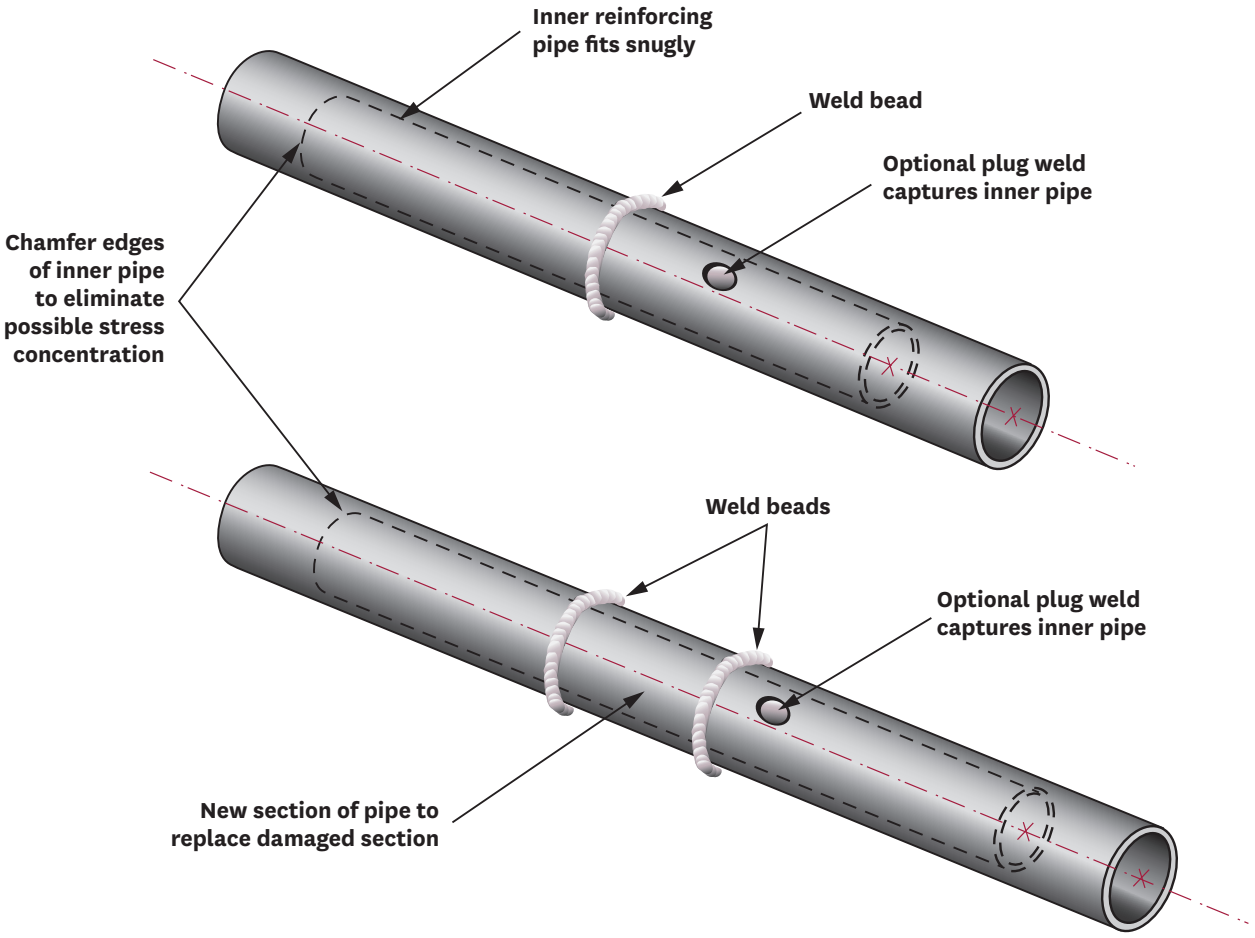
4 Weld on the patch as shown. Use no continuous welds, no end welds and no welds closer to the end of the patch piece than ¼ inch.

Six Ways to Join Pipe

Different sizes of pipe. Here are four ways to join one pipe inserted into a larger pipe by welding for a *structural* application (no fluid carried).



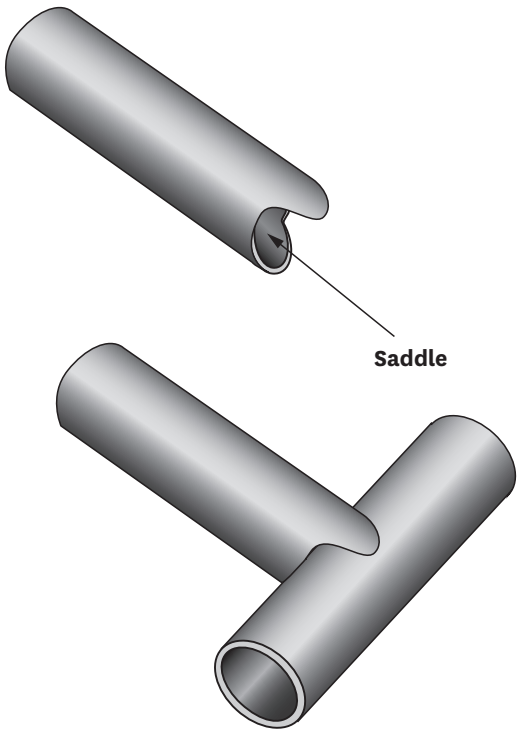
Equal-diameter pipe. To join two equal-diameter pipes in a *structural* application that will be subjected to torsion, tension, or shear, use the method shown below to ensure that the pipes are in alignment, then make a full-penetration weld. Such a weld is as strong as the pipe itself. Note that the inner pipe is for proper alignment, not strength.


Inner reinforcing pipe fits snugly
Weld bead
Optional plug weld captures inner pipe
Chamfer edges of inner pipe to eliminate possible stress concentration
Weld beads
Optional plug weld captures inner pipe
New section of pipe to replace damaged section

TUBING SADDLE

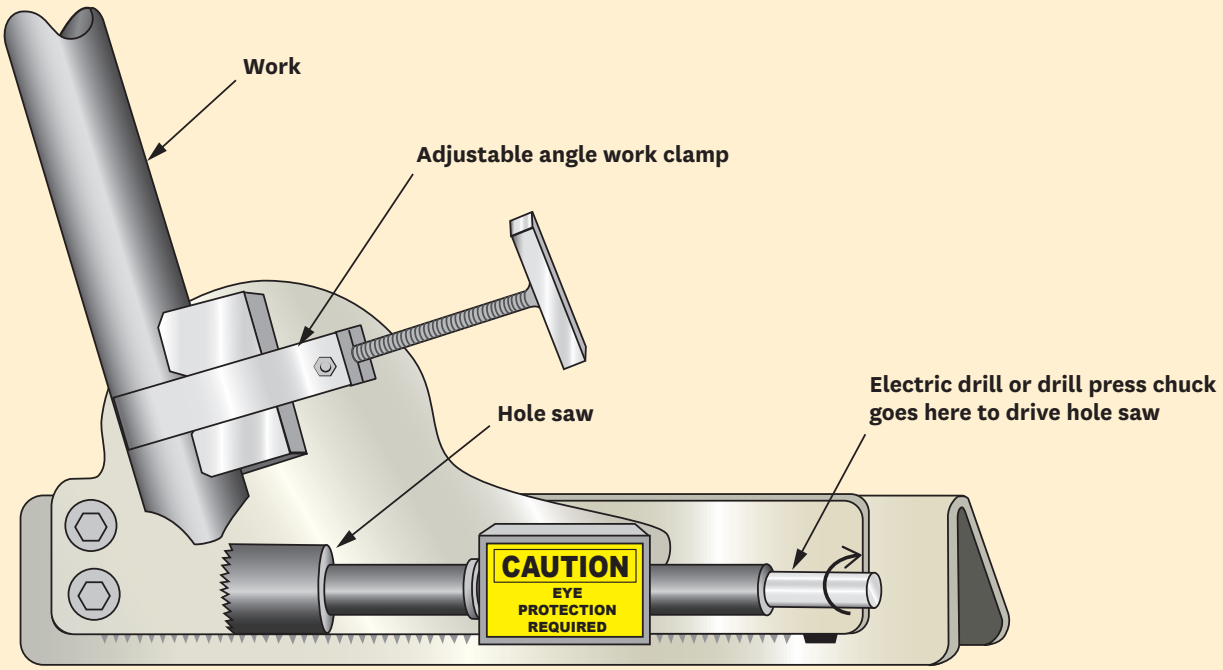
A saddle (also called a fishmouth) is the shaping of the end of one piece of tubing so it meets and fits tightly against another. This makes strong welds. The gap between the two tubing pieces should not exceed the diameter of the MIG or TIG welding wire used to make the weld.

You can use hacksaws and files to make a saddle, or use an oxyacetylene torch and an angle grinder on large-diameter or thick pipe. Begin by forming the saddle on a bench or pedestal grinder, making the final adjustments with a file. Using a hand-operated nibbling tool is a faster way to make a saddle, but this requires some skill. Another effective method is to use a saddle-cutting hole saw tool.



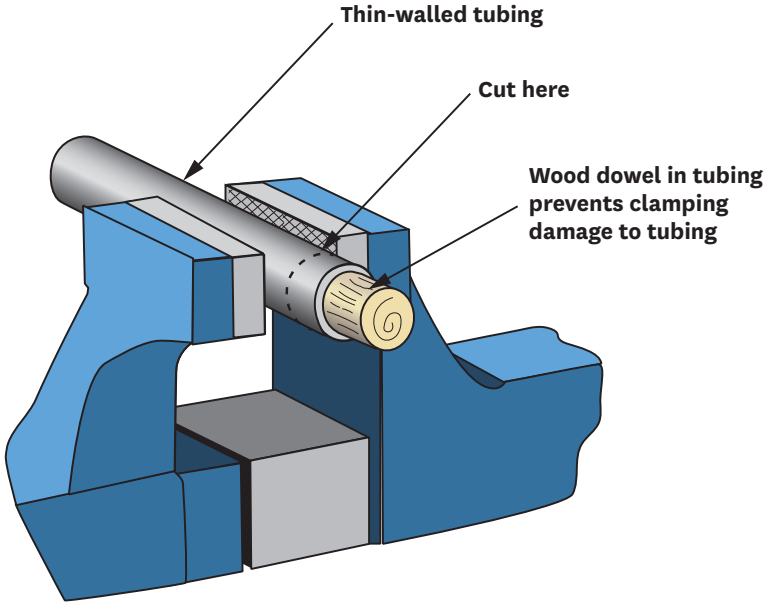
Commercial Saddle-Cutting Hole Saw Tool

A saddle-cutting hole saw tool is used in order to cut the ends of pipe so that it may fit the contour of another piece of pipe, closing the gap of the joint to be welded.



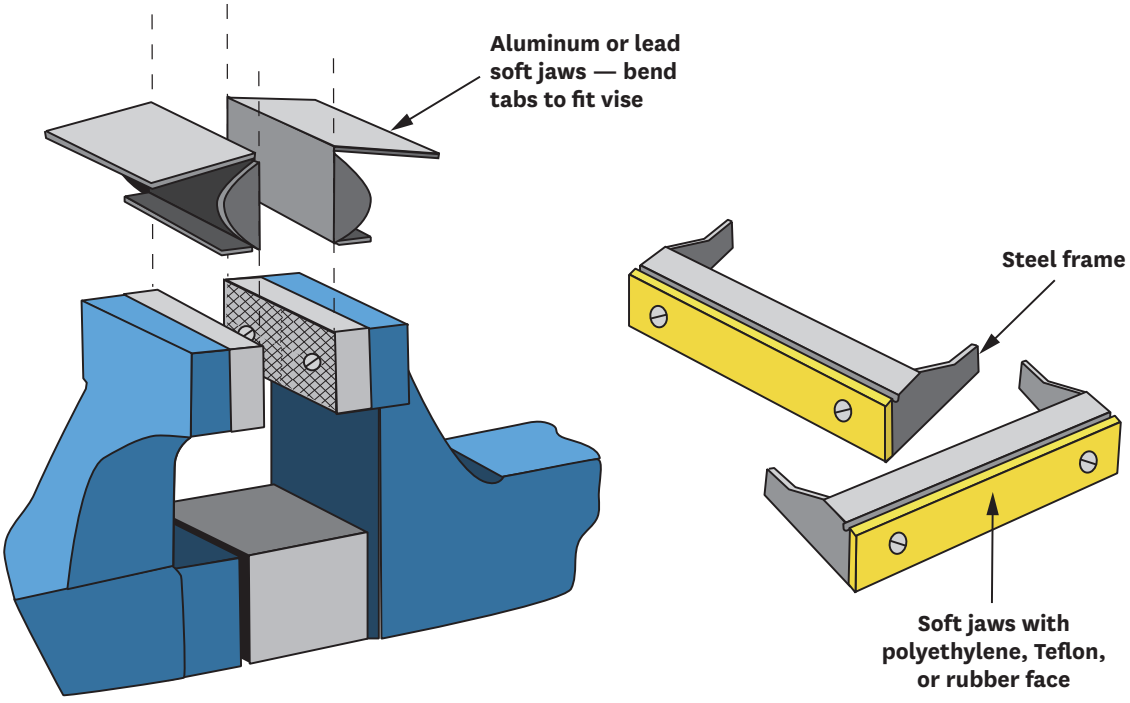
PROTECTING THIN TUBING

To protect thin-walled tubing while holding it in a vise, first insert a tight-fitting wooden dowel inside the tubing to prevent it from collapsing in the vise. Then, place soft jaws over the steel jaws of the vise to prevent marring the tubing. The soft jaws are usually made of aluminum, copper, lead, or plastic.



▲ Using a dowel when clamping thin-walled tubing prevents collapsing the tube.

▼ Soft jaws in the vise prevent damage to the work.



MATERIALS

- ½" × 44" rebar for feeder top bar
- (6) ½" × 24" rebar for vertical spindles (all but center spindle)
- (1) ½" × 22" for center vertical spindle
- (1) 3⁄16" × 1" × 32" angle iron for top mounting plate
- (1) 3⁄16" × 1" × 12" angle iron for bottom mounting plate

BUILDING A WALL-MOUNT HAY FEEDER

One of the joys of welding is that you'll discover the ability to make a wide array of farm contraptions to suit your needs. In this case we built a scaled-down version of a horse hay feeder better suited to goats. We made the openings small enough that the goats wouldn't get stuck in the bars, but large enough to hold two days of feed. This design can be easily adapted for your particular livestock.

1

Using a chop saw with a metal blade, cut materials to specified lengths.

2

Begin by bending the top bar for the feeder. Mark 10 inches on each side and bend an interior angle of approximately 110 degrees. To make the rebar easier to bend, heat it with a torch and use a vice or truck hitch to make the appropriate angle.

3

Weld the top bar to the angle iron mounting plate. Begin with tack welds, then reinforce each weld since this will need to withstand heavy use.

4

Lay out the center and two side spindles and tack weld in place. Weld in additional spindles, spacing them evenly along the base plate.

5

Mark the plates and use your cutting torch to make mounting holes on the top and bottom of the hay feeder.

6

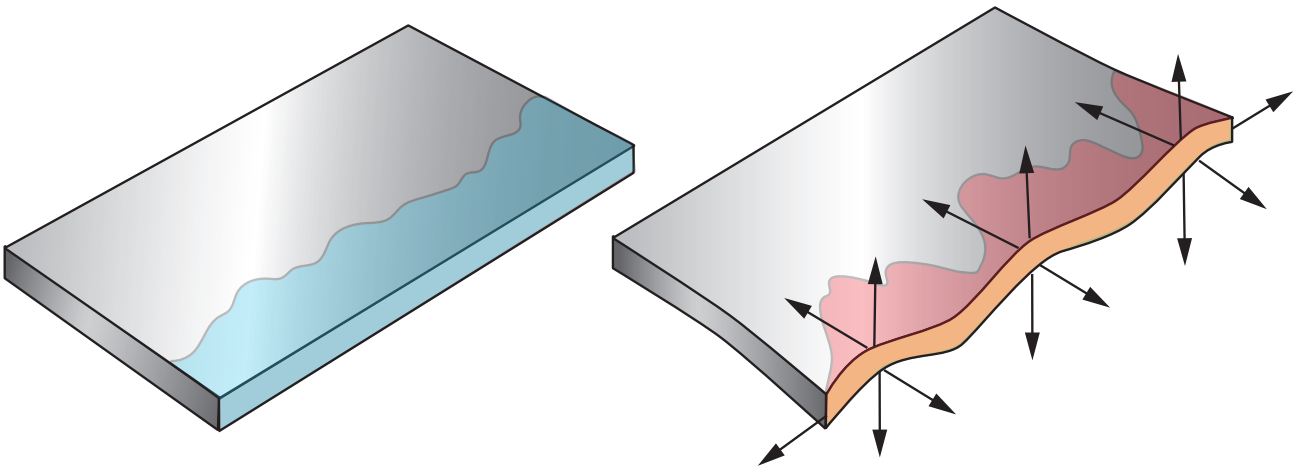
Be sure to file off all rough edges to protect livestock before putting your new hay feeder to use.

Ways to Deal with Metal Distortion

Distortion is the permanent change in shape and dimension of metal caused by expansion and contraction. Certain welding and cutting processes are sources of distortion. It is a result of residual stress left by uneven heating that causes permanent shape changes. This stress not only can ruin the shape of a part, it can also weaken it. Even if the part bears no external load, the residual stress acts as an initial load on top of what is externally imposed and reduces the total load the part can withstand.

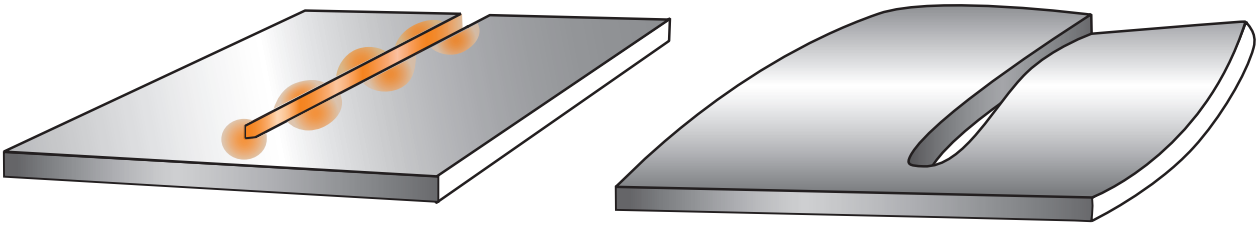
EXAMPLES OF DISTORTION

Before it is heated, a piece of sheet metal is square and flat. As one edge of the plate heats, it expands and softens, while the cool edge does not. When the sheet cools back to room temperature, most wrinkles disappear, but the sheet is permanently shorter along the heated edge. Uneven heating of the plate and the restraint offered by its cooler side cause a dimensional changed called *upsetting*. Upsetting is even more severe if a water spray cools the sheet rapidly and prevents the unheated edge from heating and expanding as the heat flows across the plate. Note that what happens during the cooling period is seldom what happens during the heating period.



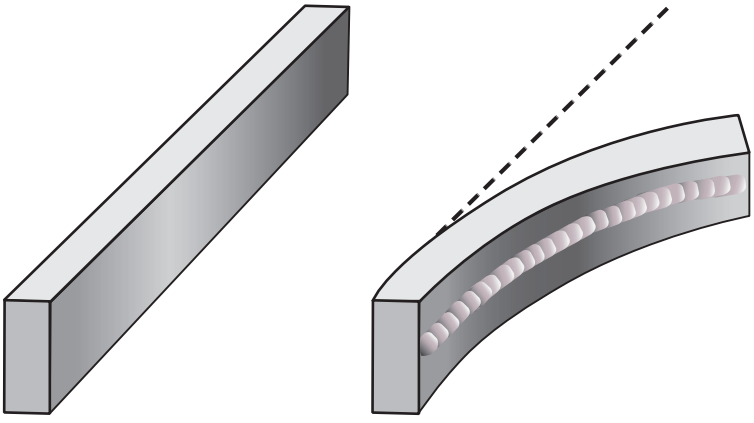
Sheet metal before heating (left) and while hot (right)

DISTORTION PRODUCED BY OXY-FUEL CUTTING. Due to differential heating and the restraint offered by the uncut portion of the plate, the *hinge effect* occurs. If two parallel cuts were made simultaneously, the metal between the cuts would show little distortion, as heating and expansion would be balanced. Such cuts can be made with dual torches.



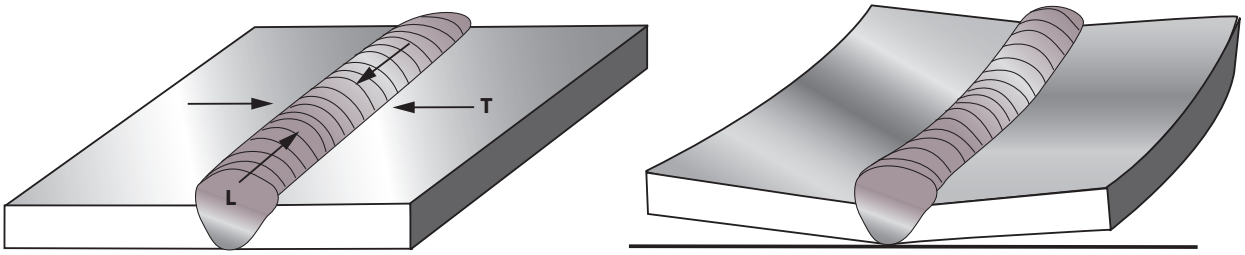
▲ Hinge effect in partially cut plate

WELD BEAD DISTORTION. As the bead is applied, one side of the bar is heated and expands. When the bar and the filler metal on top of it cool, they contract much more than the cooler metal on the bar's opposite side. Applying the weld bead makes the bar bend toward the side of the weld bead.



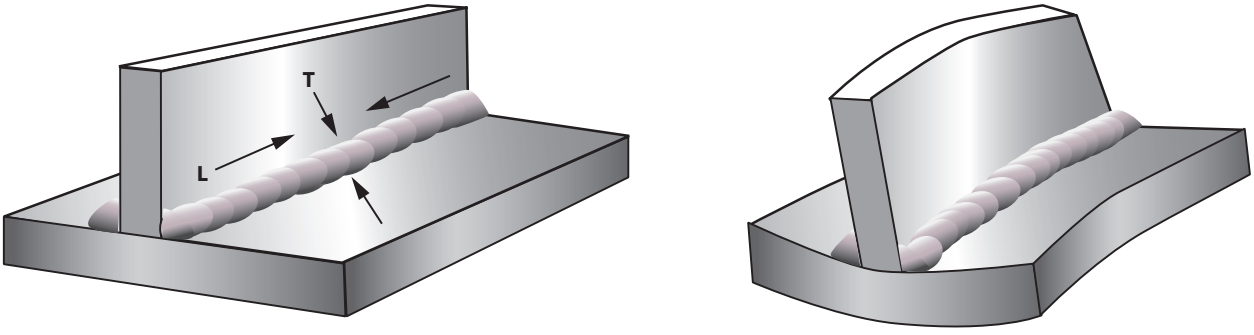
◀ Effect of applying a weld bead on one side of a steel bar: straight bar, with no bead applied (left); bar bends toward bead side with weld bead applied when cool (right)

V-GROOVE BUTT WELD DISTORTION. There are residual stresses both along the weld axis (longitudinally) and across the weld (transversely). When cooled, the weldment has permanent deformation away from the side where heat was applied along the weld line. Because this is a V-groove butt joint that has more filler metal at its top than at its root, there is more shrinkage along the top of the joint in both directions. This makes the plate dish or bend upward.



▲ Butt weld longitudinal (L) and transverse (T) residual stresses (left) and resulting deformation (right)

T-JOINT DISTORTION. There are both longitudinal and transverse stresses in the weld bead. There is a second weld bead on the back side of the T-joint. Because the longitudinal stresses on each side of the joint balance each other, the vertical member of the T-joint remains straight.



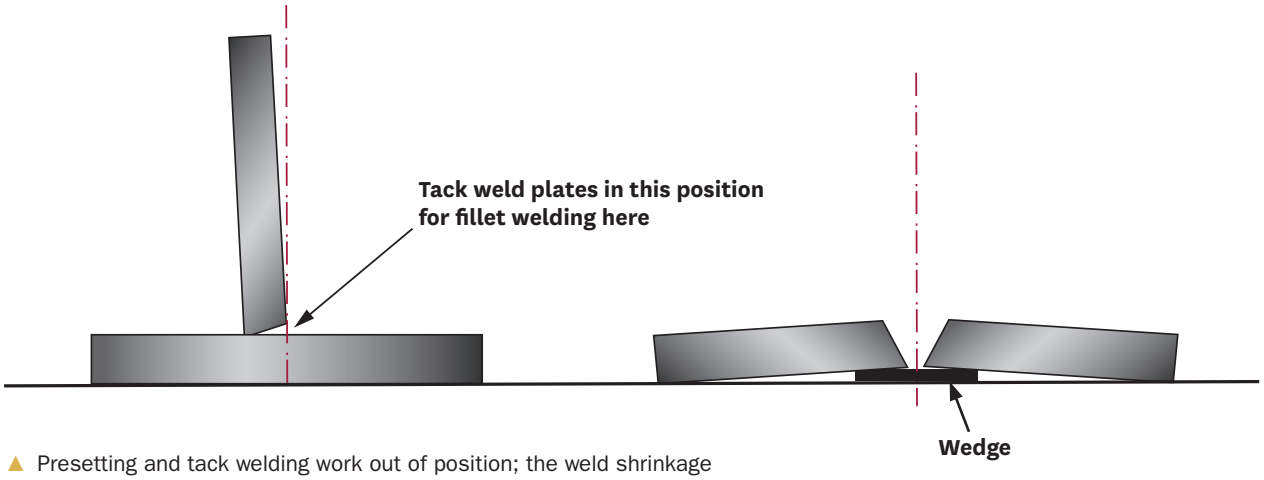
▲ Longitudinal (L) and transverse (T) stresses in a T-joint (left) and the distortion they cause (right)

CONTROLLING DISTORTION

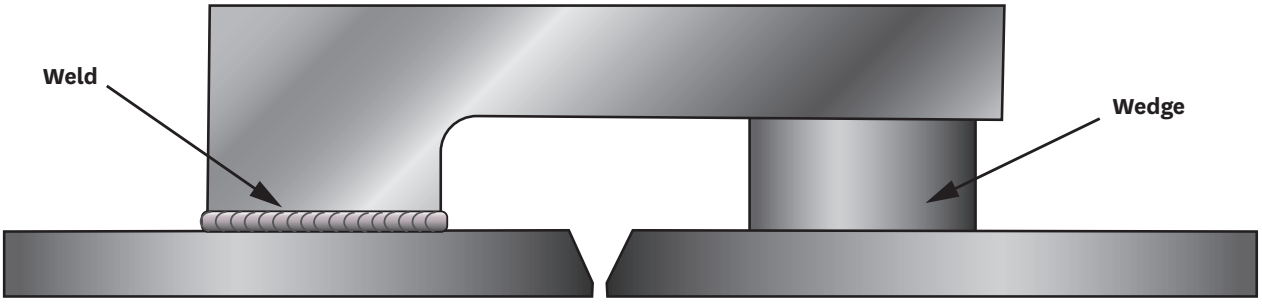
There are several techniques for reducing the effects of distortion, but keep in mind that it can never be completely eliminated.

BUTT JOINTS AND V-GROOVE JOINTS. First, preset the parts. Then, tack weld the parts slightly out of position and let residual forces bring them into proper position.

Clamping the work to an immovable object, such as a welding table, I beam, or thick plate, helps hold the piece in alignment during and after welding. You can also use wedges to hold the weld joint in proper position until the weld metal cools. This approach may not produce perfect results, but it will help reduce distortion.

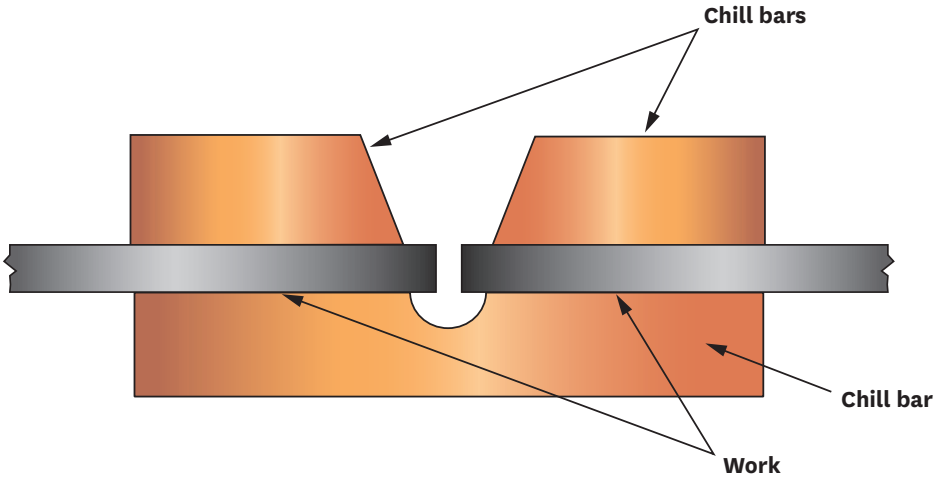


▲ Presetting and tack welding work out of position; the weld shrinkage brings the parts back into alignment



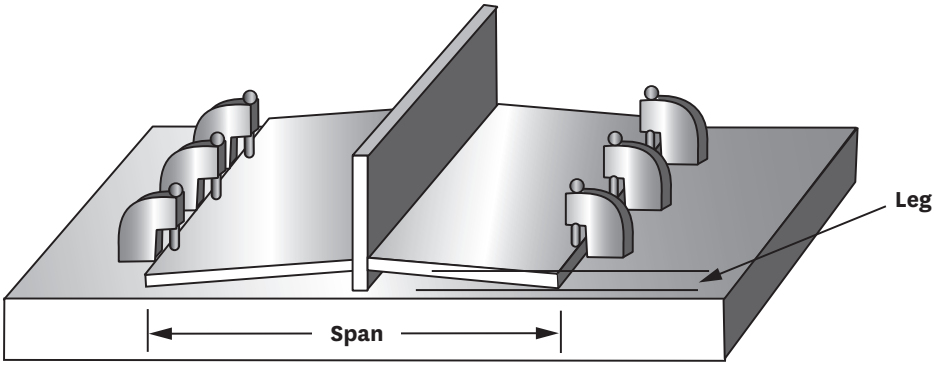
▲ Use tack-welded restraints and wedges to hold the joint in position while welding.

LIMITING HEAT FLOW WITH CHILL BARS. Chill bars consist of steel or copper bars clamped beside and parallel to the weld bead. They draw heat away from the weld and reduce its flow to the rest of the part. They also limit distortion to upsetting metal close to the weld line and eliminate ripples completely by exerting a clamping force that prevents ripples from forming when the work is hot. A groove in the lower chill bar permits the weld itself to remain hot and not have its heat drained away by the chill bar. This groove could be flooded with shielding gas for GTAW.



◀ Chill bars reduce distortion by confining heat to the weld area and by preventing work from forming ripples when hot.

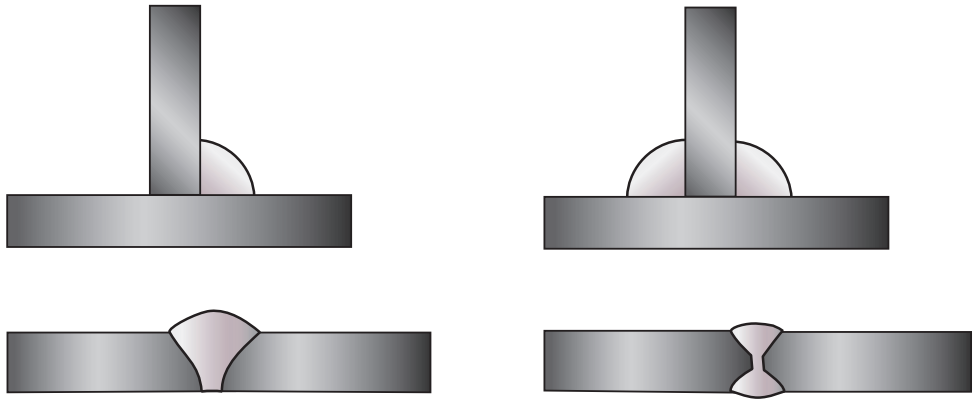
PRESTRESSING. Use clamps to bend the joint members in the opposite direction to the weld forces, letting weld-shrinkage forces bring the parts back into position. This method works well when a jig or fixture can be used and test-runs are made to determine the amount of prestress needed.



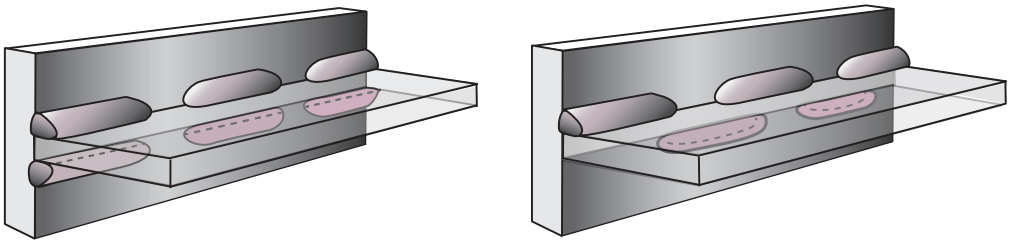
◀ Prestressing the weld joint to compensate for residual stress

BALANCING DISTORTION FORCES. Allow equal distortion forces to balance each other by using two (or more) weld beads. This can be done by putting a fillet weld on both sides of a T-joint or using a double V-groove butt joint.

Use chain intermittent or staggered intermittent weld beads. Intermittent beads not only balance one another, they also reduce the total residual force by reducing the total amount of weld bead. Even a single intermittent weld bead has less distortion than a single continuous weld bead, and often the strength of a continuous bead is not needed.

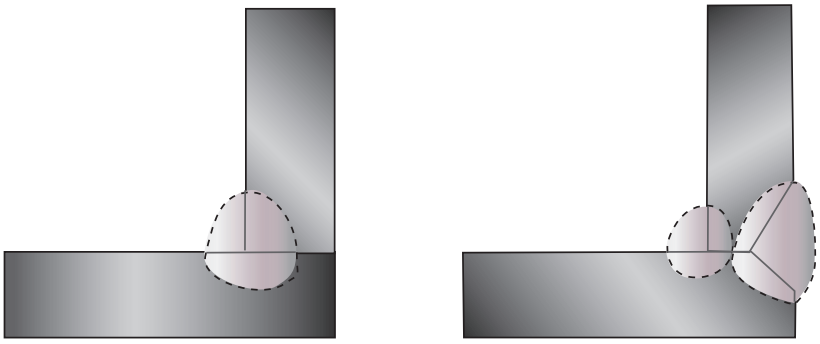


◀ Initial joint designs (left) and balanced forced designs (right)



◀ Using chain intermittent (left) or staggered intermittent welds (right) to balance forces and reduce total weld bead metal

REDESIGNING JOINTS. Use a V-groove and a fillet weld in place of a fillet weld alone to balance residual stress.



◀ Redesigned joint can balance residual stress and reduce distortion

OTHER TECHNIQUES TO REDUCE DISTORTION

Preheating base metal: Raising the temperature of the entire part or the opposite side (as in a restrained weld, such as a casting) before welding reduces temperature differences, residual stress, and distortion. You can preheat the whole thing in an oven or weld it right in your barbeque grill with the heat on. You can also post-heat the work to slow the rate of cooling, thereby reducing stress and distortion.

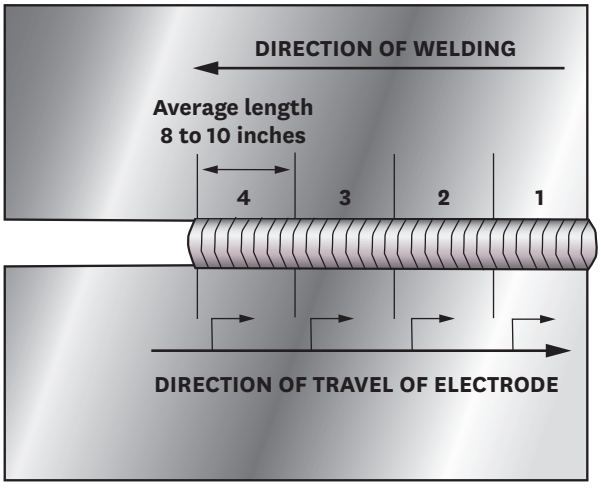
Peening: Hammering the weld metal, usually with an air hammer, slightly reshapes the metal and redistributes concentrated forces. In a multipass weld, this is done between each pass. This method can be helpful with welding objects such as castings, but its effectiveness depends on the skill and judgment of the welder; consistency with peening is difficult to control.

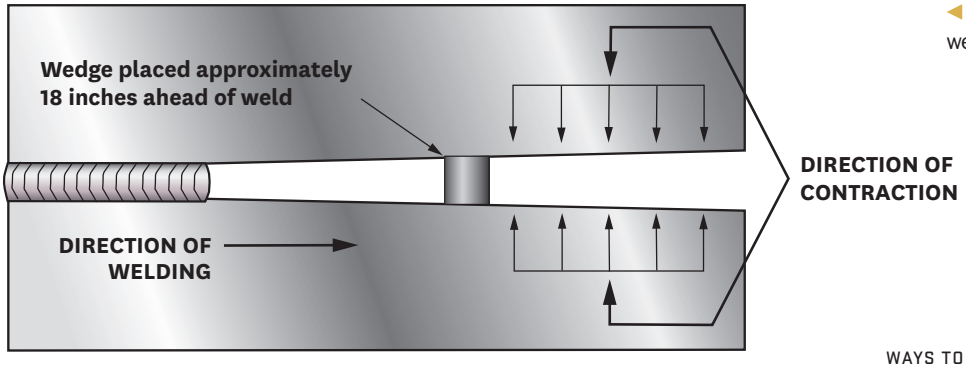
Stress-relieving heat treatment: Using an oven or electric heating coil, the entire part or the weldment area is heated high enough to remove weld-induced stress. This is commonly done in structural steel work.

Brazing or soldering instead of welding: Because brazing and soldering expose the workpiece to much lower temperatures than welding does, these two processes can be used when the strength of welding is not required and distortion is a concern.

BACK-STEP WELDING. For long, continuous beads, use back-step welding to reduce distortion. Apply short increments of beads in the direction opposite of the end point of the weld. When applying multiple passes, start and stop the beads of each layer at different points.

BACK-STEP WELDING SEQUENCE





◀ Using wedges ahead of the weld controls joint spacing.

WELDING CAST METAL

Sooner or later, you're likely to have to weld cast metal on your farm or ranch. Most machinery has cast components including transmission housings, engine blocks, and steering components. The pieces most commonly cast (as opposed to being machined out of a block of steel), are large, intricate, and often curve. The challenge in terms of welding cast metal is that it expands during the welding process because of the heat, then contracts as it cools, often creating new stress points that crack.

1

The rear differential of this old tractor is subject to extreme stress from pulling plows and other implements on the three-point hitch. A previous repair used conventional 6011 rod which resulted in more cracking. We opted to use a nickel rod, which has greater ductility, helping it to resist cracks.

To prepare to weld cast metal, start by using a grinder to vee out the crack. Our vee was about ¼ inch wide and ⅛ inch deep. It extends beyond the end of the crack about 1 inch.

2

3

Use an oxyacetylene torch to heat the area around the weld. Keep the torch moving and heat well beyond the immediate area being welded. The usage label on the electrode we were using suggested slowly heating to 800°F, which can be checked with an infrared thermometer.

4

Use a series of tack welds to help stabilize the crack. Don't weld too fast or the metal will expand excessively. Conversely, move quickly enough that the casting doesn't lose the heat from preheating. If the casting begins to cool faster than you can work, reheat with the oxy-acetylene torch.

5

Because cast metal is usually thick (⅜ inch in this case), it will take multiple passes to build up the metal.

6

You may also discover additional hairline cracks which will have to be veed out and welded as you go. Initially we only saw the crack in the top left portion of the housing, but discovered it extended several inches below. After allowing the repair to cool, we ground the weld smooth and were pleased to see no additional cracking.

7

The repaired rear differential is ground smooth before being painted.

GLOSSARY

A

acetone: A colorless, flammable, volatile liquid used as a paint remover and as a solvent for oils and other organic compounds. Used in acetylene cylinders to saturate the monolithic filler material to stabilize the acetylene.

acetylene feather: The intense white, feathery-edged portion adjacent to the cone of a carburizing oxyacetylene flame.

actual throat: The shortest distance between the weld root and the face of a fillet weld.

adhesion: A state of being stuck together. The joining together of parts that are normally separate.

alloy: A substance with metallic properties, composed of two or more chemical elements, at least one of which is a metal.

alloy steel: A plain carbon steel to which another element, other than iron and carbon, has been added in a percentage large enough to alter its characteristics.

alloying elements: Elements added in a large enough percentage to change the characteristics of the metal. Such elements may be chromium, manganese, nickel, tungsten, or vanadium; these elements are added to produce specific physical properties, such as hardness, toughness, ductility, strength, resistance to corrosion, or resistance to wear.

alternating current (AC): An electric current that reverses its direction periodically.

aluminum: One of the chemical elements; a silvery, lightweight, easily worked metal that resists corrosion.

ampere: A unit of electrical current measuring the rate of flow of electrons through a circuit. One ampere is equivalent to the current produced by one volt applied across a resistance of one ohm.

anode: The positive terminal of an electrical source.

annealing: A process of heating then cooling metal to acquire desired qualities such as ductility.

arc cutting: A group of thermal cutting processes that severs or removes metal by melting with the heat of an arc between an electrode and workpiece.

arc blow: The deflection of an arc from its normal path caused by magnetic forces.

arc force: The axial force developed by an arc plasma.

arc gap: A common term referring to arc length.

arc gouging: Thermal gouging that uses a type of arc cutting process to form a bevel or groove.

arc plasma: A gas that has been heated by an arc to at least a partially ionized condition, enabling it to conduct electric current.

arc time: The time during which an arc is maintained in making an arc weld.

arc welding: A group of welding processes in which fusion is produced by heating with an electric arc or arcs with or without the application of pressure and with or without the use of filler metal.

arc voltage: The voltage across the arc.

ASTM: American Society for Testing and Materials.

autogenous weld: A fusion weld made without using a filler material.

AWS: American Welding Society.

axis of a weld: A line through the length of a weld, perpendicular to and at the geometric center of its cross section.

B

back bead: A weld bead resulting from a back weld pass. Back beads are made after the primary weld is completed.

backfire: The momentary recession of the flame into the welding tip or cutting tip, followed by immediate reappearance or complete extinction of the flame; accompanied by a loud, popping report.

backgouging: The removal of weld metal and base metal from the weld root side of a welded joint to facilitate complete fusion and complete joint penetration upon subsequent welding from that side.

backhand welding: A welding technique in which the welding torch or gun is directed opposite to the progress of welding.

backing: Material or a device placed against the back side of a joint to support and retain molten weld metal. The material may be partially fused or remain unfused during welding and may be either metal or nonmetal (metal strip, asbestos, carbon, copper, inert gas, ceramics).

backing bead: A weld bead resulting from a backing pass. Backing beads are completed before welding the primary weld.

backing pass: A weld pass made to provide a backing for the primary weld.

backing strip: A common term used to describe a backing on the root side of the weld in the form of a strip.

back-step sequence: A longitudinal sequence in which weld passes are made in the direction opposite to weld progression, usually used to control distortion.

back weld: A weld made at the back of a single-groove weld.

base material: The material that is welded, brazed, soldered, or cut.

base metal: The metal or alloy that is welded, brazed, soldered, or cut.

bead weld: A term used for surfacing welds.

bevel: An edge preparation; the resulting angular edge shape.

bevel angle: The angle between the bevel of a joint member and a plane perpendicular to the surface of the member.

boxing: The continuation of a fillet weld around a corner of a member as an extension of the principal weld.

brazing: A group of welding processes that produces coalescence of materials by heating them to the brazing temperature in the presence of a filler metal having a liquidus above 840ºF (450ºC) and below the solidus of the base metal. The filler metal is distributed between the closely fitted faying surfaces of the joint by capillary action.

brazing filler metal: The metal or alloy used as a filler metal in brazing, which has a liquidus above 840˚F (450˚C) and below the solidus of the base metal.

buckling: Bending or warping caused by the heat of welding.

butt joint: A joint between two members aligned approximately in the same plane.

C

capillary action: The force by which liquid in contact with a solid is distributed between closely fitted surfaces of the joint to be brazed or soldered.

carbon: A nonmetallic chemical element that occurs in many inorganic and all organic compounds. Carbon is found in diamond and graphite and is a constituent of coal, petroleum, asphalt, limestone, and other carbonates. In combination, it occurs as carbon dioxide and as a constituent of all living things. Adjustment of the amount of carbon in iron produces steel.

carbon steel: A steel containing various percentages of carbon. Low-carbon steel contains a maximum of 0.15 percent carbon; mild steel contains 0.15 to 0.35 percent carbon; medium-carbon steel contains 0.35 to 0.60 percent carbon; high-carbon steel contains 0.60 to 1.0 percent carbon.

carburizing flame: A reducing oxygen-fuel gas flame in which there is an excess of fuel gas, resulting in a carbon-rich zone extending around and beyond the inner cone of the flame.

cast iron: A family of alloys, containing more than 2 percent carbon and between 1 and 3 percent silicon. Cast irons are not malleable when solid, and most have low ductility and poor resistance to impact loading. There are four basic types of cast iron: gray, white, ductile, and malleable.

cathode: The negative terminal of a power supply; the electrode when using direct current electrode negative (DCEN).

chain intermittent weld: An intermittent weld on both sides of a joint where the weld increments on one side are approximately opposite those on the other side.

chromium: A lustrous, hard, brittle, steel-gray metallic element used to harden steel alloys; used in production of stainless steel and as a corrosion-resistant plating.

cladding: A surfacing method that deposits or applies surfacing material, usually to improve resistance to corrosion or heat.

coalescence: The growing together or growth into one body of the materials being welded.

coefficient of thermal expansion: The increase in length per unit length for each degree a metal is heated.

cohesion: The result of a perfect fusion and penetration when the molecules of the parent material and the added filler materials thoroughly integrate, as in a weld.

cold crack: A crack that develops after solidification is complete.

cold work/working: Forming, bending, or hammering a metal well below the melting point. Cold working of metals causes hardening, making them stronger but less ductile.

complete joint penetration: A root condition in a groove weld in which weld metal extends through the joint thickness.

composite: A material consisting of two or more discrete materials with each material retaining its physical identity.

composite electrode: A generic term for multi-component filler metal electrodes in various physical forms, such as stranded wires, tubes, or covered wire.

concavity: The maximum distance from the face of a concave fillet weld perpendicular to a line joining the weld toes (edges of the weld). A concave fillet weld has a face that is contoured below a straight line between the two toes of a fillet weld.

conductor: A device, usually a wire, used to connect or join one electrical circuit or terminal to another.

cone: The conical part of an oxygen-fuel gas flame adjacent to the tip orifice.

constant-current (CC) power source: An arc welding power source with a volt-ampere relationship yielding a small welding current change from a large arc voltage change.

constant-voltage (CV) power source: An arc welding power source with a volt-ampere relationship yielding a large welding current change from a small arc voltage change.

constricted arc: A plasma arc column that is shaped by the constricting orifice in the nozzle of the plasma arc torch or plasma spraying gun.

consumable electrode: An electrode that provides filler metal, which is consumed in the arc welding process.

consumable insert: Filler metal that is placed at the joint root before welding, and is intended to be completely fused into the joint root to become part of the completed weld.

contact resistance: Resistance to the flow of electric current between two workpieces or between an electrode and a workpiece.

convexity: The maximum distance from the face of a convex fillet weld perpendicular to a line joining the toes.

corner joint: A joint between two members located approximately at right angles to each other in the form of an L.

covered electrode: A composite filler metal electrode consisting of a core of a bare electrode or metal cored electrode to which a covering sufficient to provide a slag layer on the weld metal has been applied. The covering may contain materials providing such functions as shielding from atmosphere, deoxidation, and arc stabilization and can serve as a source of metallic additions to the weld.

cover plate: A removable pane of colorless glass, plastic-coated glass, or plastic that covers the filter plate and protects it from weld spatter, pitting, and scratching.

cracking a valve: Rapidly opening and closing a valve to clear the orifice of unwanted foreign material.

crater: A depression in the weld face at the termination of a weld bead.

cutting attachment: A device for converting an oxygen-fuel gas welding torch into an oxygen-fuel cutting torch.

cutting head: The part of a cutting attachment to which the cutting torch or tip may be attached.

cutting tip: An attachment to an oxygen-fuel cutting torch from which the gases exit.

D

deposited metal: Filler metal that has been added during welding, brazing, or soldering.

deposition rate: The speed at which the filler material can be deposited by a given electrode or welding wire, measured in pounds per hour.

depth of fusion: The distance that fusion extends into the base metal or previous bead from the surface melted during welding.

direct current electrode negative (DCEN): The arrangement of direct current arc welding cables in which the electrode is the negative pole and the workpiece is the positive pole of the welding arc.

direct current electrode positive (DCEP): The arrangement of direct current arc welding cables in which the electrode is the positive pole and the workpiece is the negative pole of the welding arc.

distortion: Non-uniform expansion and contraction of metal caused by heating and cooling during the welding process.

downhill: Welding in a downward progression.

drag: During thermal cutting, the offset distance between the actual and straight line exit points of the gas stream or cutting beam measured on the exit surface of the base metal.

drag angle: The travel angle when the electrode is pointing in a direction opposite to the progression of welding. This angle can also be used to partially define the positions of guns, torches, and rods.

ductility: The tendency to stretch or deform appreciably before fracturing.

duty cycle: The percentage of time during an arbitrary test period that a power source or its accessories can be operated at rated output without overheating. Most welding machines are rated in intervals of 10 minutes. For example, a duty cycle of 50 percent means the machine can be operated at a given amperage setting for 5 continuous minutes without damage to the equipment; 60 percent would give 6 minutes; 70 percent would give it 7 minutes.

E

edge joint: A joint between the edges of two or more parallel or nearly parallel members.

edge preparation: The preparation of the edges of the joint members, by cutting, cleaning, plating, or other means.

effective throat: The minimum distance, minus any convexity, between the weld root and the face of a fillet weld.

electrode: A component of the electrical welding circuit that terminates at the arc, molten conductive slag, or base metal.

electrode angle: The angle of the electrode in relationship to the surface of the material being welded; the electrode's perpendicular angle to the metal's surface leaning toward the direction of travel.

electrode classification: A means of identifying electrodes by their usability, flux coverings, and chemical makeup. The American Welding Society publishes a series of specifications for consumables used in welding processes.

electrode holder: A device used for mechanically holding and conducting current to an electrode during welding or cutting.

electrode lead: The electrical conductor between the source of arc welding current and the electrode holder.

F

face reinforcement: Weld reinforcement on the side of the joint from which welding was done.

faying surface: The mating surface of a member that is in contact with or in close proximity to another member to which it is to be joined.

filler material: The material, metal, or alloy to be added in making a welded, brazed, or soldered joint.

fillet weld: A weld of approximately triangular cross section joining two surfaces approximately at right angles to each other in a lap joint, T-joint, or corner joint.

fillet weld leg: The distance from the joint root to the toe of the fillet weld.

fillet weld size: For equal-leg fillet welds, the leg lengths of the largest isosceles right triangle that can be inscribed within the fillet weld cross section. For unequal-leg fillet welds, the leg lengths of the right triangle that can be inscribed within the fillet weld cross section.

filter plate: An optical material that protects the eyes against excessive ultraviolet, infrared, and visible radiation. Also called filter glass or filter lens.

filter plate shade: Refers to the lens darkness number, which indicates the darkness of the lens. The higher the number, the darker the lens.

fixture: A device designed to hold and maintain parts in proper relation to each other.

flame propagation rate: The speed at which flame travels through a mixture of gases.

flare V-groove weld: A weld in a groove formed by two members with curved surfaces.

flashback: A recession of the flame back into the mixing chamber of the oxygen-fuel gas torch or flame spraying gun.

flashback arrester: A device to limit damage from a flashback by preventing propagation of the flame from beyond the location of the arrester.

flat welding position: The welding position used to weld from the upper side of the joint at a point where the weld axis is approximately horizontal and the weld face lies in an approximately horizontal plane.

flaw: An undesirable blemish or discontinuity in a weld, such as a crack or porosity.

flux: A material used to hinder or prevent the formation of oxides and other undesirable substances in molten metal and on solid metal surfaces, and to dissolve or otherwise facilitate the removal of such substances.

flux-cored electrode: A composite tubular filler metal electrode consisting of a metal sheath and a core of various powdered materials; produces an extensive slag cover on the face of a weld bead. External shielding may be required when using flux-cored electrodes.

forehand welding: A welding technique in which the welding torch or gun is directed toward the progress of welding.

fuel gas: A gas, such as acetylene, natural gas, hydrogen, propane, stabilized methylacetylene propadiene, and other fuels, normally used with oxygen in one of the oxy-fuel processes and for heating.

fusible plug: A metal alloy plug that closes the discharge channel of a gas cylinder and is designed to melt at a predetermined temperature, permitting the escape of gas.

fusion: The joining of base material, with or without filler material, by melting them together.

fusion face: A surface of the base metal that will be melted during welding.

fusion welding: Any welding process that uses fusion of the base metal to make the weld.

fusion zone: The area of base metal as determined on the cross section of a weld.

G

gas cylinder: A portable container used for transportation and storage of compressed gas.

gas nozzle: A device at the exit end of the torch or gun that directs shielding gas.

gas regulator: A device for controlling the delivery of gas at a substantially constant pressure.

globular transfer: In arc welding, the transfer of molten metal in large drops from a consumable electrode across the arc.

GMAW: Gas metal arc welding process; common terms are MIG (metal inert gas), MAG (metal active gas), wire feed, and hard wire welding.

goggles: Protective glasses equipped with filter plates set in a frame that fits snugly against the face; used primarily with oxygen-fuel gas welding processes.

groove angle: The total included angle of the groove between workpieces.

groove face: The surface of a joint member included in the side of the groove from root to toe.

groove weld: A weld made in a groove between the workpieces.

groove weld size: The joint penetration of a groove weld. Also called groove throat or effective throat.

ground connection: An electrical connection of the welding machine frame to the earth for safety.

GTAW: Gas tungsten arc welding process; common terms are TIG (tungsten inert gas) and Heliarc.

H

hardfacing: A surfacing method in which hard material is deposited to reduce wear.

heat-affected zone (HAZ): The portion of the base metal in which mechanical properties or microstructure have been altered by the heat of welding, brazing, soldering, or thermal cutting.

high-carbon steel: *See* carbon steel.

horizontal welding position: In a fillet weld, the welding position in which the weld is on the upper side of a horizontal surface and against a vertical surface. In a groove weld, the welding position in which the weld face lies in an approximately vertical plane, and the weld axis at the point of welding is approximately horizontal.

I

impact strength: The ability of a material to resist shock, dependent on both the strength and ductility of the material.

inclusion: Entrapped foreign solid material, such as slag, flux, tungsten, or oxide.

inert gas: A gas that normally does not combine chemically with other elements or compounds.

intermittent weld: A weld in which the continuity is broken by recurring unwelded spaces.

interpass temperature: In a multipass weld, the temperature of the weld area between weld passes.

inverter power supply: A welding power supply with solid-state electrical components that change the incoming 60 Hz power to a higher frequency. Changing the frequency allows for the use of a smaller, lighter-weight transformer. Inverter power supplies can be used with all arc welding processes.

iron carbide: A binary compound of carbon and iron; it becomes the strengthening constituent in steel.

iron soldering: A soldering process in which the heat required is obtained from a soldering iron.

J

J-groove weld: A type of groove weld where one side of the joint forms a J.

joint: The junction of members or the edges of members that are to be joined or have been joined.

joint clearance: The distance between the faying surfaces of a joint in brazing or soldering.

joint design: The shape, dimensions, and configuration of a joint.

joint efficiency: The ratio of strength of a joint to the strength of the base metal, expressed in percent.

joint geometry: The shape and dimensions of a joint in cross section prior to welding.

joint penetration: The distance the weld metal extends from the weld face into a joint, exclusive of weld reinforcement.

joint root: That portion of a joint to be welded where the members approach closest to each other. In cross section, the joint root may be a point, a line, or an area.

joint spacer: A metal part, such as a strip, bar, or ring, inserted in the joint root to serve as a backing and to maintain the root opening during welding.

joint type: One of five basic joint configurations: butt joint, corner joint, edge joint, lap joint, and T-joint.

K

kerf: The width of a cut produced during a cutting process.

keyhole welding: A technique in which a concentrated heat source penetrates partially or completely through a workpiece, forming a hole (or keyhole) at the leading edge of the weld pool. As the heat source progresses, the molten metal fills in behind the hole to form the weld bead.

L

lamination: A type of discontinuity with separation or weakness generally aligned parallel to the worked surface of a metal.

lap joint: A joint between two overlapping members in parallel planes.

laser beam cutting (LBC): A thermal cutting process that severs metal by locally melting or vaporizing with the heat from a laser beam.

lens shade: *See* filter plate shade.

liquidus: The lowest temperature at which a metal or an alloy is completely liquid.

longitudinal crack: A crack with its major axis orientation approximately parallel to the weld axis.

M

manual welding: Welding with the torch, gun, or electrode holder held and manipulated by hand; may involve accessory equipment, such as part motion devices and manually controlled filler material feeders.

medium-carbon steel: *See* carbon steel.

melt-through: Visible root reinforcement produced in a joint welded from one side.

metal cored electrode: A composite tubular filler metal electrode consisting of a metal sheath and a core of various powdered materials.

metal electrode: A filler or nonfiller metal electrode used in arc welding or cutting; consists of a metal wire or rod that is either bare or covered with a suitable covering or coating.

metallic bond: The principal atomic bond that holds metals together.

metallurgy: The science explaining the properties, behavior, and internal structure of metals.

methylacetylene propadiene: A family of alternative fuel gases that are mixtures of two or more gases (propane, butane, butadiene, methylacetylene, and propadiene). Methylacetylene propadiene is used for oxy-fuel cutting, heating, brazing, and soldering.

MIG: *See* GMAW.

mild steel: *See* carbon steel.

mixing chamber: That part of a welding or cutting torch in which a fuel gas and oxygen are mixed.

multipass weld: A weld requiring more than one pass to ensure complete and satisfactory joining of the metal pieces.

N

neutral flame: An oxy-fuel gas flame that has characteristics neither oxidizing nor reducing.

nitrogen: A gaseous element that occurs freely in nature and constitutes about 78 percent of Earth's atmosphere. Colorless, odorless, and relatively inert, although it combines directly with magnesium, lithium, and calcium when heated with them. Produced either by liquefaction and fractional distillation of air, or by heating a water solution of ammonium nitrate.

nonconsumable electrode: An electrode that does not provide filler metal, as used in the GTAW process.

noncorrosive flux: A soldering flux that, in either its original or residual form, does not chemically attack the base metal; typically composed of rosin-based materials.

normalizing: The process of heating a metal above a critical temperature and allowing it to cool slowly under room temperature conditions to obtain a softer and less distorted material.

O

ohm: A unit of electrical resistance. One ohm is equal to the resistance of a circuit in which a potential difference of one volt produces a current of one ampere.

open-circuit voltage: The voltage between the output terminals of the power source when no current is flowing to the torch or gun.

open root joint: An unwelded joint without backing or consumable insert.

overlap: The protrusion of weld metal beyond the weld toe or weld root.

oxidizing flame: An oxy-fuel flame in which there is an excess of oxygen, resulting in an oxygen-rich zone extending around and beyond the cone.

oxygen: A colorless, odorless, tasteless, gaseous chemical element. Oxygen occurs free in the atmosphere, forming one-fifth of its volume, and in combination in water, sandstone, limestone, and so on. Oxygen is very active and is able to combine with nearly all other elements. It is essential to life.

P

parent metal: A common term referring to the base metal.

partial joint penetration weld: A joint root condition in a groove weld in which incomplete joint penetration exists.

pass: A single progression of welding along a joint, resulting in a weld bead or layer.

peening: The mechanical working of metals using impact blows.

penetration: A common term used in describing depth of fusion, joint penetration, or root penetration.

phase transitions: When metals or metal alloys go from solid to liquid or the reverse. These changes are also called allotropic transformations.

pilot arc: A low-current arc between the electrode and the constricting nozzle of the plasma arc torch to ionize the gas and facilitate the start of the welding arc.

plasma arc cutting (PAC): An arc cutting process that uses a constricted arc and removes the molten metal with a high-velocity jet of ionized gas issuing from the constricting orifice.

plug weld: A weld made in a circular hole in one member of a joint, fusing that member to another member.

polarity: The condition of being positive or negative with respect to some reference point or object. In welding, the terminals of the power supply are designated negative and positive; whichever terminal is hooked to the electrode determines polarity.

positive pressure torch: The positive pressure torch requires that gases be delivered at pressures above 2 psi. In the case of acetylene, the pressure should be between 2 and 15 psi. Oxygen is generally supplied at approximately the same pressure for welding.

power source: An apparatus for supplying current and voltage suitable for welding, thermal cutting, or thermal spraying.

precipitate: To cause (something) to become insoluble, with heat or a chemical reagent, and to separate from a solution.

preform: Brazing or soldering filler metal fabricated in a shape or form for a specific application.

preheat: The heat applied to the base metal or substrate to attain and maintain preheat temperature.

pressure regulator: A device designed to maintain a nearly constant supply pressure. Regulators may be attached to pressurized cylinders, gas generators, or pipelines to reduce pressure as desired to operate equipment.

protective atmosphere: A gas or vacuum envelope surrounding the workpieces, used to prevent or reduce the formation of oxides and other detrimental surface substances, and to facilitate their removal.

pulsed-power welding: An arc welding process in which the power is cyclically programmed to pulse so that effective but short duration values of power can be utilized. Such short duration values are significantly different from the average value of power. Equivalent terms are pulsed-voltage or pulsed-current welding.

purging: The removing of any unwanted gas or vapor from a container, chamber, hose, torch, or furnace.

push angle: The travel angle when the electrode is pointing in the direction of the weld progression. This angle can also be used to partially define the positions of welding guns.

Q

quenching: The sudden cooling of heated metal by immersion in water, oil, or other liquid. The purpose of quenching is to produce desired strength properties in hardenable steel.

R

reactor: A device used in arc welding circuits to minimize or smooth irregularities in the flow of the welding current; also called an inductor.

reducing flame: An oxy-fuel flame with an excess of fuel gas.

resistor: A device with measurable, controllable, or known electrical resistance used in electronic circuits or in arc welding circuits to regulate the arc amperes.

root bead: A weld bead that extends into or includes part or all of the joint root.

root face: The portion of the groove face within the joint root.

root opening: A separation at the joint root between the workpieces.

root penetration: The distance the weld metal extends into the joint root.

root reinforcement: Weld reinforcement opposite the side from which welding was done.

runoff weld tab: Additional material that extends beyond the end of the joint on which the weld is terminated.

S

safety disc: A disc in the back side of a high-pressure cylinder valve designed to rupture and release gas to the atmosphere, preventing cylinder rupture if the cylinder is mishandled.

seal weld: Any weld designed primarily to provide a specific degree of tightness against leakage.

seam weld: A continuous weld made between or upon overlapping members, in which coalescence may start and occur on the faying surfaces, or may have proceeded from the outer surface of one member. The continuous weld may consist of a single weld bead or a series of overlapping spot welds.

shear: To tear or wrench by shearing stress; to cut through using a cold cutting tool when shearing metal.

shielding gas: Protective gas used to prevent or reduce atmospheric contamination.

short-circuiting transfer: Metal transfer in which molten metal from a consumable electrode is deposited during repeated short circuits.

silicon: A nonmetallic element resembling graphite in appearance and used extensively in alloys. Silicon is usually found in the oxide (silicate) form. Silicon contributes to the strength of low-alloy steels and increases hardenability, along with performing the valuable function of a deoxidizer to eliminate trapped gas.

silicon rectifier: A silicon semiconductor device that acts like a check valve for electricity and is used to change alternating current to direct current.

single-phase: A generator or circuit in which only one alternating current voltage is produced.

slag: A nonmetallic product resulting from the mutual dissolution of flux and nonmetallic impurities in some welding and brazing processes.

slope: A term used to describe the shape of the static volt-ampere curve of a constant-voltage welding machine. Slope is caused by impedance and is usually introduced by adding substantial amounts of inductance to the welding power circuit. As more inductance is added to a welding circuit, there is a steeper slope to the volt-ampere curve. The added inductance limits the available short-circuit current and slows the rate of response of the welding machine to changing arc conditions.

slot weld: A weld made in an elongated hole in one member of a joint, fusing that member to another member. The hole may be open at one end.

slugging: The addition of metal, such as a length of rod, to a joint before welding or between passes, often resulting in a weld with incomplete fusion.

solder: The metal or alloy used as a filler metal in soldering, which has a liquidus not exceeding 840ºF (450ºC) and below the solidus of the base metal.

soldering: A group of welding processes that produce coalescence of materials by heating them to the soldering temperature and using a filler metal having a liquidus not exceeding 840ºF (450ºC) and below the solidus of the base metals. The filler metal is distributed between closely fitted faying surfaces of the joint by capillary action.

soldering iron: A soldering tool having an internally or externally heated metal bit usually made of copper.

solder interface: The interface between solder metal and the base metal in a soldered joint.

solder metal: The portion of a soldered joint that has melted during soldering.

solidus: The highest temperature at which a metal or an alloy is completely solid.

spacer strip: A metal strip or bar prepared for a groove weld that is inserted in the joint root to serve as a backing and to maintain the root opening during welding. It can also bridge an exceptionally wide root opening due to poor fit.

spatter: The metal particles expelled during fusion welding that do not form a part of the weld.

spliced joint: A joint in which an additional workpiece spans the joint and is welded to each member.

spool: A filler metal package consisting of a continuous length of welding wire in coil form wound on a cylinder (called a barrel), which is flanged at both ends. The flange contains a spindle hole of smaller diameter than the inside diameter of the barrel.

spot weld: A weld made between or upon overlapping members in which coalescence may start and occur on the faying surfaces or may proceed from the outer surface of one member. The weld cross section is approximately circular.

spray transfer: Metal transfer in which molten metal from a consumable electrode is propelled axially across the arc in small droplets.

staggered intermittent weld: An intermittent weld on both sides of a joint with the weld increments on one side alternating with respect to those on the other side.

standoff distance: The distance between a welding nozzle and the workpiece.

steel: A material composed primarily of iron, less than 2 percent carbon, and (in an alloy steel) small percentages of other alloying elements.

step-down transformer: A transformer that reduces the incoming voltage.

step-up transformer: A transformer that increases the incoming voltage.

stickout: In GTAW, the length of the tungsten electrode extending beyond the end of the gas nozzle. In GMAW and FCAW, the length of the unmelted electrode extending beyond the end of the contact tube.

strain: Distortion or deformation of a metal structure due to stress.

stress: A force causing or tending to cause deformation in metal. A stress causes strain.

stringer bead: A type of weld bead made without appreciable weaving motion.

stub: The short length of filler metal electrode, welding rod, or brazing rod that remains after its use for welding or brazing.

substrate: Any material to which a thermal spray deposit is applied.

surface preparation: The operation necessary to produce a desired or specified surface condition.

surfacing: The application by welding, brazing, or thermal spraying of a layer of material to a surface to obtain desired properties or dimensions, as opposed to making a joint.

surfacing weld: A weld applied to a surface, as opposed to making a joint, to obtain desired properties or dimensions.

sweat soldering: A soldering process variation in which workpieces that have been precoated with solder are reheated and assembled into a joint without the use of additional solder (also called sweating).

T

tack weld: A weld made to hold the parts of a weldment in proper alignment until the final welds are made.

tensile strength: The resistance to breaking exhibited by a material when subjected to a pulling stress; measured in pounds per square inch.

thermal conductivity: The ability of a material to transmit heat.

thermal cutting (TC): A group of cutting processes that severs or removes metal by localized melting, burning, or vaporizing of the workpieces.

thermal expansion: The expansion of materials caused by heat input.

thermal stress relieving: A process of relieving stresses by uniform heating of a structure or a portion of a structure, followed by uniform cooling.

tinning: A common term for precoating.

T-joint: A joint between two members located approximately at right angles to each other in the form of a T.

torch brazing (TB): A brazing process that uses heat from a fuel-gas flame.

torch oscillation: Moving a torch in a back-and-forth motion.

torch soldering (TS): A soldering process that uses heat from a fuel-gas flame.

transferred arc: A plasma arc established between the electrode of the plasma arc torch and the workpiece.

transverse crack: A crack with its major axis oriented approximately perpendicular to the weld axis.

travel angle: The angle less than 90 degrees between the electrode axis and a line perpendicular to the weld axis, in a plane determined by the electrode axis and the weld axis. This angle can also be used to partially define the positions of welding guns, torches, rods, and beams.

tungsten electrode: A nonfiller metal electrode used in arc welding, arc cutting, and plasma spraying; made principally of tungsten.

U

under-bead crack: A crack in the heat-affected zone, generally not extending to the surface of the base metal.

undercut: A groove melted into the weld face or root surface and extending below the adjacent surface of the base metal.

underfill: A condition in which the weld face or root surface extends below the adjacent surface of the base metal.

uphill: Welding with an upward progression.

V

vertical welding position: The welding position in which the weld axis, at the point of welding, is approximately vertical, and the weld face lies in an approximately vertical plane.

vertical-up: A common term for uphill welding.

volt: A unit of electrical force or potential.

W

waster plate: A piece of metal used to initiate thermal cutting.

watt: A unit of electric power equal to voltage multiplied by amperage. One horsepower is equal to 746 watts.

weave bead: A type of weld bead made with transverse oscillation.

weld: A localized coalescence of metal or nonmetals produced either by heating the materials to the welding temperature, with or without the application of pressure, or by the application of pressure alone, with or without the use of filler material.

weldability: The capacity of material to be welded, under imposed fabrication conditions, into a specific suitably designed structure and to perform satisfactorily in the intended service.

weld axis: A line through the length of the weld, perpendicular to and at the geometric center of its cross section.

weld bead: A weld resulting from a pass.

weld crack: A crack located in the weld metal or heat-affected zone.

welder certification: Written verification that a welder has produced welds meeting a prescribed standard of welder performance.

weld face: The exposed surface of a weld on the side from which welding was done.

weld groove: A channel in the surface of a workpiece or an opening between two joint members that provides space to contain a weld.

welding: A joining process that produces coalescence of materials by heating them to the welding temperature with or without the application of pressure, or by the application of pressure alone, with or without the use of filler metal.

welding arc: A controlled electrical discharge between the electrode and the workpiece that is formed and sustained by the establishment of a gaseous, conductive medium called an arc plasma.

welding electrode: A component of the welding circuit through which current is conducted and that terminates at the arc, molten conductive slag, or base metal.

welding filler metal: The metal or alloy to be added in making a weld joint that alloys with the base metal to form weld metal in a fusion-welded joint.

welding helmet: A device equipped with a filter plate designed to be worn on the head to protect the eyes, face, and neck from arc radiation, radiated heat, spatter, or other harmful matter expelled during some welding and cutting processes.

welding leads: The workpiece lead (cables) and electrode lead (cables) of an arc welding circuit.

welding positions: The relationship between the weld pool, joint, joint members, and welding heat source during welding.

welding power source: An apparatus for supplying current and voltage suitable for welding.

welding procedure: The detailed methods and practices involved in the production of a weldment.

welding rectifier: A device, usually a semiconductor diode, in a welding power source for converting alternating current to direct current.

welding rod: A form of welding filler metal, normally packaged in straight lengths, that does not conduct the welding current.

welding schedule: A written statement, usually in tabular form, specifying values of parameters and welding sequence for performing a welding operation.

welding sequence: The order of making welds in a weldment.

welding transformer: A transformer used for supplying current for welding.

welding wire: A form of welding filler metal, normally packaged as coils or spools, that may or may not conduct electrical current, depending upon the welding process with which it is used.

weld interface: The interface between weld metal and base metal in a fusion weld, between base metals in a solid-state weld without filler metal, or between filler metal and base metal in a solid-state weld with filler metal.

weldment: An assembly consisting of component parts joined by welding.

weld metal: The portion of a fusion weld that has been completely melted during welding.

weld metal area: The area of weld metal as measured on the cross section of a weld.

weld pass: A single progression of welding along a joint. The result of a pass is a weld bead or layer.

weld pass sequence: The order in which the weld passes are made.

weld penetration: A common term for joint penetration and root penetration.

weld pool: The localized volume of molten metal in a weld prior to its solidification as a weld metal.

weld puddle: A common term for weld pool.

weld reinforcement: Weld metal in excess of the quantity required to fill a joint.

weld root: The points, shown in a cross section, at which the root surface intersects the base metal surfaces.

weld tab: Additional material that extends beyond either end of the joint, on which the weld is started or terminated.

weld toe: The junction of the weld face and the base material.

wetting: The phenomenon whereby a liquid filler metal or flux spreads and adheres in a thin, continuous layer on a solid base metal.

wiped joint: A joint made with solder having a wide melting range and with the heat supplied by the molten solder poured onto the joint. The solder is manipulated with a handheld cloth or paddle to obtain the required size and contour.

wire feed speed: The rate at which wire is consumed in arc cutting, thermal spraying, or welding.

work angle: The angle less than 90 degrees between a line perpendicular to the major workpiece surface and a plane determined by the electrode axis and the weld axis. In a T-joint or a corner joint, the line is perpendicular to the nonbutting member. This angle can also be used to partially define the positions of guns, torches, rods, and beams.

work hardening: Also called cold working; the process of forming, bending, or hammering a metal well below the melting point to improve strength and hardness.

workpiece: The part that is welded, brazed, soldered, thermal cut, or thermal sprayed.

workpiece lead: The electrical conductor between the arc welding current source and workpiece connection.

wrought iron: A material composed almost entirely of iron, with very little or no carbon.

Y

yield strength: The load at which a material will begin to yield, or permanently deform; also referred to as yield point.

METRIC CONVERSIONS

Length

To convert	to	multiply
inches	millimeters	inches by 25.4
inches	centimeters	inches by 2.54
inches	meters	inches by 0.0254
feet	meters	feet by 0.3048
feet	kilometers	feet by 0.0003048
yards	centimeters	yards by 91.44
yards	meters	yards by 0.9144
yards	kilometers	yards by 0.0009144
miles	meters	miles by 1,609.344
miles	kilometers	miles by 1.609344

Temperature

To convert	to	
Fahrenheit	Celsius	subtract 32 from Fahrenheit temperature, multiply by 5, then divide by 9

US	Metric
⅛ inch	3.2 mm
¼ inch	6.35 mm
⅜ inch	9.5 mm
½ inch	1.27 cm
⅝ inch	1.59 cm
¾ inch	1.91 cm
⅞ inch	2.22 cm
1 inch	2.54 cm
1.5 inch	3.81 cm
2 inch	5.08 cm
2.5 inch	6.35 cm
3 inch	7.62 cm
3.5 inch	8.89 cm
4 inch	10.16 cm
4.5 inch	11.43 cm
5 inch	12.70 cm
5.5 inch	13.97 cm
6 inch	15.24 cm
6.5 inch	16.51 cm
7 inch	17.78 cm
7.5 inch	19.05 cm
8 inch	20.32 cm
8.5 inch	21.59 cm
9 inch	22.86 cm
9.5 inch	24.13 cm
10 inch	25.40 cm

US	Metric
11 inch	27.94 cm
12 inch	30.48 cm
13 inch	33.02 cm
14 inch	35.56 cm
15 inch	38.10 cm
16 inch	40.64 cm
17 inch	43.18 cm
18 inch	45.72 cm
19 inch	48.26 cm
20 inch	50.80 cm
21 inch	53.34 cm
22 inch	55.88 cm
23 inch	58.42 cm
24 inch	60.96 cm
25 inch	63.50 cm
26 inch	66.04 cm
27 inch	68.58 cm
28 inch	71.12 cm
29 inch	73.66 cm
30 inch	76.20 cm
31 inch	78.74 cm
32 inch	81.28 cm
33 inch	83.82 cm
34 inch	86.36 cm
35 inch	88.90 cm
36 inch	91.44 cm

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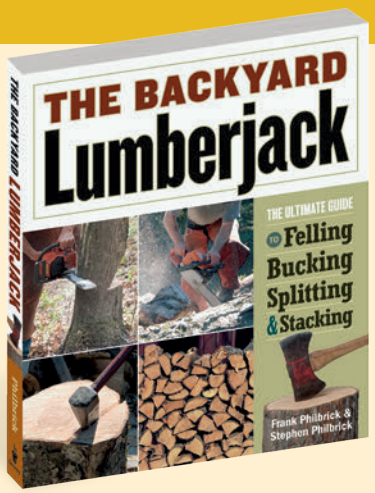

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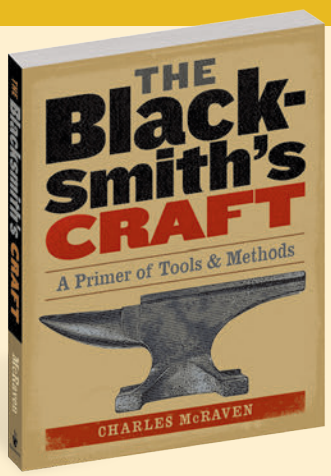

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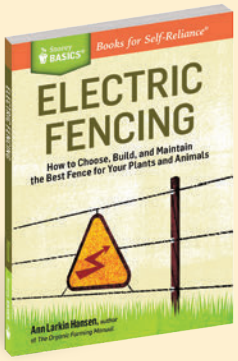
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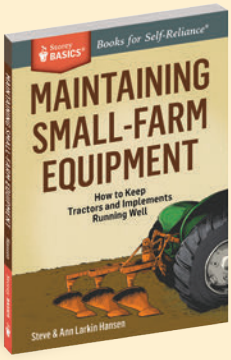
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